SEVENTH ANNUAL NATIONAL

CONFERENCE

PROCEEDINGS

17-18 MAY 1956

SHOREHAM HOTEL, WASHINGTON, D. C.

JOHN A. NEVROS, *Proceedings Chairman*

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TO THOSE ATTENDING THE SEVENTH ANNUAL NATIONAL CONFERENCE AND CONVENTION OF THE AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS. I EXTEND WARM GREETINGS. I APPLAUD YOUR ORGANIZATION'S CONTINUING EFFORT TO UPHOLD HIGH STANDARDS IN YOUR FIELD AND TO ENCOURAGE YOUNG PEOPLE TO TRAIN FOR ENGINEERING AND SCIENTIFIC CAREERS. ALL OF YOU HAVE MY BEST WISHES FOR AN INFORMATIVE SERIES OF DELIBERATIONS=

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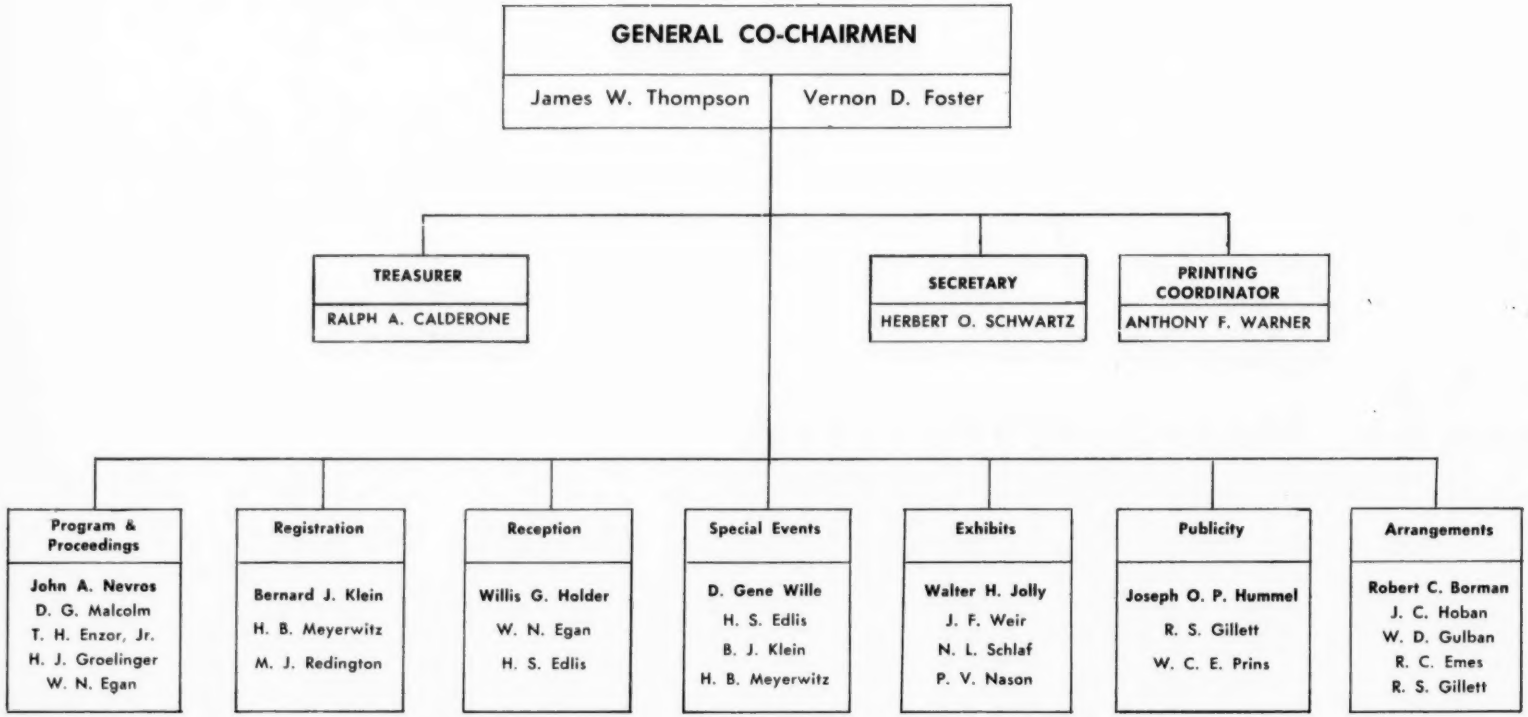

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THURSDAY MAY 17

8:00 — **REGISTRATION — Terrace Foyer**

9:00 — **Terrace Banquet Room**

CALL TO ORDER—**Vernon D. Foster, General Co-Chairman**

INVOCATION—**DR. FREDERICK BROWN HARRIS, Chaplain of the United States Senate**

WELCOME TO CONFERENCE—**James W. Thompson, General Co-Chairman**

KEYNOTE ADDRESS—INDUSTRIAL ENGINEERING IN TRANSITION
DONALD G. MALCOLM, Past President, A.I.I.E.; Director of Operations Research, Booz, Allen and Hamilton, Chicago, Illinois.

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	Session 1A — IE's LABOR-MGMT. ROLE **Main Ballroom**	**Session 1B — WORK STUDY** **Terrace Banquet Room**	**Session 1C** **West Ballroom** **OPTIMIZING INDUSTRIAL ENGINEERING**
	CHAIRMAN: Dr. Gerald Nadler, Vice-President, A.I.I.E. for the Mid-west Region; Professor and Head, Department of Industrial Engineering, Washington University, St. Louis, Mo.	**CHAIRMAN: Robert H. Roy, Dean, School of Engineering, The Johns Hopkins University, Baltimore, Md.**	**CHAIRMAN: Joseph O. P. Hummel, Director of Membership, A.I.I.E.; Senior Staff Member, Operations Research Office, The Johns Hopkins University, Chevy Chase, Md.**
10:00	THE DEVELOPING RELATIONSHIP BETWEEN COLLECTIVE BARGAINING AND INDUSTRIAL ENGINEERING SINCE THE CLOSE OF WORLD WAR II DR. WILLIAM GOMBERG, Director, Management Engineering Department, International Ladies' Garment Workers' Union, AFL-CIO, New York, N.Y., Adjunct Professor, Industrial Engineering, Columbia University.	MEMO-MOTION — A PRACTICAL INDUSTRIAL ENGINEERING ANALYSIS TECHNIQUE SAMUEL W. EARLE, Industrial Engineering Section, Management Services Department, Union Carbide and Carbon Corporation, New York, N. Y.	ORGANIZING FOR INDUSTRIAL ENGINEERING FREDERICK M. GILBRETH, McKinsey & Company, Management Consultants, New York, N. Y.
10:45	MANAGEMENT'S VIEWPOINT OF IE's ROLE JOHN L. SCHWAB, President, John L. Schwab Associates, Management Consultants, Bridgeport, Conn.	OBJECTIVE TIME STUDY WITH STATISTICAL CONTROLS CLARENCE J. ALLEN, Chief Industrial Engineer, Cudahy Brothers Company, Cudahy, Wisconsin.	UTILIZING THE INDUSTRIAL ENGINEERING POTENTIAL IN MEDIUM-SIZED MANUFACTURING PLANTS C. LLOYD THORPE, General Manager, Willamette Iron and Steel Company, Portland, Ore.
11:30	**QUESTIONS and DISCUSSION**	**QUESTIONS and DISCUSSION**	**QUESTIONS and DISCUSSION**
12:15	**LUNCHEON** **Blue Room**	CHAIRMAN: John A. Nevros, Director, Washington, D. C., Chapter, AIIE; Chief, Management Assistance Branch, Office of The Quartermaster General, Department of the Army, Washington, D. C.	MANAGEMENT DEVELOPMENT FOR INDUSTRIAL ENGINEERS DR. JOHN J. CORSON, Partner, McKinsey & Company, Management Consultants, and Manager of the Washington, D. C. Office.
	Session 2A — MATHEMATICAL PROGRAMMING **Main Ballroom**	**Session 2B — WORK MEASUREMENT** **Terrace Banquet Room**	**Session 2C** **West Ballroom** **AUTOMATIC DATA PROCESSING SYSTEMS**
	CHAIRMAN: Dr. Robert N. Lehrer, Editor-in-Chief, Journal of Industrial Engineering; Professor of Industrial Engineering, Georgia Institute of Technology, Atlanta, Ga.	**CHAIRMAN: Walter R. Turkes, Assistant Dean, School of Engineering and Mines, Professor and Head, Industrial Engineering Department, University of Pittsburgh, Pittsburgh, Pa.**	**CHAIRMAN: Herbert J. Groelinger, Senior Systems Engineer, National Cash Register Co., Hawthorne, Calif.**
2:00	INDUSTRIAL APPLICATIONS OF "MP" NYLES V. REINFELD, Managing Director, National Institute of Management, Inc., Mgmt. Consultants, Cleveland, Ohio.	PROBLEMS OF WORK MEASUREMENT RALPH PRESGRAVE, Vice-President, J. D. Woods and Gordon, Ltd., Management Consultants; Vice-President, York Knitting Mills, Ltd., Toronto, Canada.	IMPLICATIONS OF CURRENT DEVELOPMENT TRENDS DR. SAMUEL N. ALEXANDER, Chief, Data Processing Systems Division, National Bureau of Standards, Washington, D. C.
2:45	"MP" ON A "DO-IT-YOURSELF" BASIS JOHN P. JUNG, Methods Engineer and Director of Trg. for the Industrial Engineering Department of the Television and Radio Division, Philco Corporation, Philadelphia, Pa.	AUTO-MEASUREMENT — SOME NEW APPROACHES TO WORK MEASUREMENT GORDON R. EWING, Industrial Engineer, R.R. Donnelley & Sons Company, Chicago, Ill.	ORGANIZING FOR AUTOMATIC DATA PROCESSING DR. ELBERT P. LITTLE, Staff Consultant of Anderson-Nichols and Company, Management Consultants, Boston, Mass.
3:30	ILLUSTRATIONS OF LINEAR PROGRAMMING DR. HAROLD W. KUHN, Associate Professor of Mathematics, Bryn Mawr College, Bryn Mawr, Pa.	INDIRECT WORK STANDARDS DR. H. B. MAYNARD, President, Methods Engineering Council, Management Consultants, Pittsburgh, Pa.	SKILLS REQUIRED FOR APPLICATION OF ADPS DR. HOWARD AIKEN, Director, The Computation Laboratory of Harvard University, Cambridge, Mass.
4:15	**QUESTIONS and DISCUSSION**	**QUESTIONS and DISCUSSION**	**QUESTIONS and DISCUSSION**
5:30	**SOCIAL HOUR — Louis Seize Room**		
7:00	**BANQUET** **Terrace Banquet Room**	CHAIRMAN: E. L. Siegle, National President, A.I.I.E.; Superintendent, Wire and Wire Products, Columbia—Geneva Steel Division, United States Steel Corporation, Pittsburg, California.	LABOR-MANAGEMENT AND THE PROBLEMS AND PROMISE OF TOMORROW WALTER P. REUTHER, Vice President, AFL-CIO, and President, International Union, United Automobile, Aircraft & Agricultural Implement Workers of America—UAW, Detroit, Michigan.

FRIDAY MAY 18

	FUNDAMENTALS	CURRENT PRACTICES	NEW CHALLENGES
	Session 3A — APPLIED MATHEMATICS **Main Ballroom** **CHAIRMAN: William N. Egan, Vice-President, A.I.I.E., for North East Region; Consulting Industrial Engineer, Washington, D. C.**	**Session 3B — AUTOMATION & SHOP TECHNIQUES** **Terrace Banquet Room** **CHAIRMAN: Matt A. Payne, Past President, A.I.I.E.; General Manager, Lubrizol of Canada, Ltd., Niagara Falls, Ontario, Canada**	**Session 3C — HUMAN ENGINEERING** **West Ballroom** **CHAIRMAN: Winston C. E. Prins, Industrial Consulting Engineer, Fairchild Camera and Instrument Corporation, Syosset, Long Island, N. Y.**
9:00	SOME APPLICATIONS OF PROBABILITY THEORY TO MANUFACTURING PROBLEMS DR. ROBERT B. FETTER, Asst. Prof. of Industrial Management, Massachusetts Institute of Technology, Cambridge, Mass.	PROGRAM CONTROLS FOR USE WITH MACHINE TOOLS (Controls That Think and Act Automatically) HARRY L. PALMER, Manager-Engineering, Specialty Control Department, General Electric Company, Waynesboro, Va.	MAN AS A LINK IN COMPLEX MACHINE SYSTEMS DR. G. H. MOWBRAY, Applied Physics Laboratory of the Johns Hopkins University in Silver Spring, Md.
9:45	APPLICATIONS OF MONTE CARLO METHOD IN SYSTEMS ANALYSIS STROTHER WALKER, Group Chairman, Operations Research Office, The Johns Hopkins University, Chevy Chase, Md.	THIS IS AUTOMATION An informative new film presentation of latest concepts and applications of automation—General Electric Company.	DESIGN AND MANAGEMENT OF ACTION GROUPS DR. LEE S. CHRISTIE, Group Chairman, Operations Research Office, The Johns Hopkins University, Chevy Chase, Md.
10:30	BOUNDING THE SOLUTIONS OF PRACTICAL QUEUEING PROBLEMS BY ANALYTIC METHODS DR. GLEN D. CAMP, Consultant to the President, Melpar, Inc., Falls Church, Va.	NOISE AND VIBRATION CONTROL DONALD H. VANCE, Vice-President and Executive Engineer, The Korfund Company, Inc., Long Island City, N. Y.	PERCEPTION AND ANTHROPOMETRICS DR. ROBERT B. SLEIGHT, President, Applied Psychology Corporation, Washington, D. C.
11:15	**QUESTIONS and DISCUSSION**	**QUESTIONS and DISCUSSION**	**QUESTIONS and DISCUSSION**
12:15	**L U N C H E O N** **Blue Room**	CHAIRMAN: F. F. Groseclose, Past President, A.I.I.E.; Director, School of Industrial Engineering, Georgia Institute of Technology, Atlanta, Georgia	THE RESEARCH PROGRAM OF THE AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS DR. ANDREW S. SCHULTZ, JR., Director of Research, A.I.I.E., Prof. and Head, Department of Industrial and Engineering Administration, Cornell University, Ithaca, N. Y.
	Session 4A — CONTROL TECHNIQUES **Blue Room** **CHAIRMAN: Nelson P. Greller, President, Nelson P. Greller Associates, Consulting Engineers, Washington, D. C.**	**Session 4B** **OPERATIONS RESEARCH APPLICATIONS** **Terrace Banquet Room** **CHAIRMAN: Willis G. Holder, Chief Industrial Engineer, Columbus General Depot, U. S. Army, Columbus, Ohio**	**Session 4C** **INDUSTRIAL ENGINEERING IN GOVERNMENT** **West Ballroom** **CHAIRMAN: Herbert S. Edlis, Industrial Engineer, Mgmt. Division, Office of The Quartermaster General of the Army, Washington, D.C.**
2:00	DIFFERENTIAL PROFIT CONTROL DR. RAYMOND VILLERS, Consultant in Industrial Mgmt.; Associate Prof. of Industrial Engineering at Stevens Institute of Technology, Hoboken, N. J., and lecturer in Industrial Engineering at Columbia University, New York, N. Y.	OPERATIONS RESEARCH IN ORGANIZATION PLANNING: A CASE STUDY DR. RUSSELL L. ACKOFF, Associate Prof., Director, Operations Research Group, Case Institute of Tech., Cleveland, O.	TOOLING-UP FOR SCIENTIFIC WORK MSMT. 2:00 JOHN A. NEVROS, Chief, Mgmt. Assistance Br., Mgmt. Div., OQMG, Dept. of the Army, Washington, D. C.
2:45	MEASURING WORK BY SAMPLING METHODS DR. RALPH M. BARNES, Prof. of Engineering and Production Mgmt., University of California, Los Angeles, Calif.	SYSTEMS SIMULATION WARREN E. ALBERTS, Director of Industrial Engineering, United Airlines, Chicago, Ill.	DEVELOPMENT OF MANAGEMENT CONTROLS 2:30 DR. IRWIN P. LAZARUS, Acting Director, Ord. Mgmt. Engg. Trg. Program, Rock Island Arsenal, Ill.
3:30	LINEAR DECISION RULES IN PRODUCTION AND INVENTORY CONTROL JOHN F. MUTH, Instructor of Economics, Carnegie Institute of Technology, Pittsburgh, Pa.	OPERATIONS RESEARCH IN ACCOUNTING DR. ROGER R. CRANE, Manager of Research, Mgmt. Sciences, Touche, Niven, Bailey & Smart, Certified Public Accountants, Detroit, Mich.	I. E. APPLICATION TO MISSILES RESEARCH 3:00 JOSEPH C. MOQUIN, Chief Industrial Engineer, Army Ballistic Missile Agency, Huntsville, Ala.
4:15	**QUESTIONS and DISCUSSION**	**QUESTIONS and DISCUSSION**	USE OF ENGINEERED STANDARDS IN OVERHEAD OPERATIONS 3:30 LT. L. L. KORNFELD, Supply Corps, U. S. Navy, Mgmt. Engg. Div., Bureau Supplies and Accts., Dept of the Navy. 4:15 **QUESTIONS and DISCUSSION**

SATURDAY MAY 19

A.I.I.E. NATIONAL CONVENTION
SATURDAY, MAY 19, 1956
WEST BALLROOM

9:00	CONVENTION SESSION
12:15	LUNCHEON—CHAIRMAN: E. L. SLAGLE, PRESIDENT OF A.I.I.E. PRESIDENTIAL KEYNOTE ADDRESS: HOWARD P. EMERSON, PRESIDENT-ELECT OF A.I.I.E.
2:00	CONVENTION SESSION CONTINUED

FOREWORD

We extend our sincere thanks and appreciation to the speakers who made the 7th Annual National Conference of the American Institute of Industrial Engineers the outstanding success that it was. Without them there could not have been a conference.

Each speaker contributed most generously of his time, talents and technical knowledge. In addition, the requirement for editing and submitting a paper or transcript of his remarks for publication in these proceedings, although a significant contribution, constituted an extra personal burden.

It had been our original plan and desire to publish these proceedings prior to the Conference. Unfortunately only approximately forty percent of the speakers were able to provide us with papers in advance. The rest of the papers were received subsequent to the conference, with the last arriving early in September.

We recognize the pressures and demands on the time of our speakers and appreciate that they found time to review and edit their papers so they could be included herein. It is only through the splendid cooperation of our speakers that we are able to document the 7th Annual National Conference for posterity and bring it to a fitting conclusion. We thank each and everyone of them.

1956 Conference and Convention Committee

OPERATIONS RESEARCH IN ORGANIZING PLANNING: A CASE STUDY
(Five Year Planning for an Integrated Organization*)

Russell L. Ackoff**
Director, Operations Research Group
Case Institute of Technology
Cleveland, Ohio

BACKGROUND

The reorganization of the General Electric Company into operating departments has been discussed extensively in magazines, journals, and A.M.A. publications. As has been reported the company has been organized into five operating groups, 22 divisions, and over 100 operating departments.

The problem discussed in this paper involves one of these 22 divisions, the Lamp Division. This business, older than the General Electric Company itself, was one of the original parts out of which the company was founded. In the last quarter of the century this lamp business has grown at a rate 50% greater than that of the gross national product. It employs approximately 15,000 people in 37 manufacturing plants, 36 sales districts, 20 warehouses, and its headquarters. It is a business which is engaged not only in the manufacturing of light bulbs but also in the production of the parts that go into the finished lamp, and a large part of the equipment used in manufacturing these lamps and parts.

From its inception the Lamp Division followed the now popular theory of decentralization. Its operating decisions were made on the firing line. Instructions to its operating managers were in the form of very brief, one-page bulletins explaining only what cannot be done

* Reprinted from Proceeding of the Conference on "Case Studies in Operations Research," Case Institute of Technology, Cleveland, 1956.

** This paper jointly prepared by Walter S. Glover, Manager, Finance, Photo Lamp Department, Lamp Division, General Electric Co., and Russel L. Ackoff, Director, Operations Research Group, Case Institute of Technology, Cleveland, Ohio, and presented at the AIIE 7th Annual National Conference by Dr. Ackoff.

by them. With the exception of only a few decision areas the running of the business was in the hands of the managers of operating units.

At the time this study began the Division was organized on purely functional lines. The Vice-President and General Manager of the Division had reporting to him administrators in charge of marketing, manufacturing, engineering, finance, employee relations, and law. The marketing manager, for example, was responsible for product-planning, distribution, sales, advertising, and all other marketing functions for more than 15,000 different product types. These product types were sold and distributed to many diverse customers through many diverse channels.

The manufacturing administrator, to take another example, was responsible for the development of manufacturing processes, for the administration of the policies under which the various plants were operating, and for the production of the finished products to very, very exacting standards.

As in many other industries, the quality of a finished product is determined to a very large degree by the quality of the components. In order to increase high quality standards, the Division has manufactured its own parts for many years. Up to 1955 the Division had within its manufacturing group the Glass Department, the Parts Department, and the Lamp Assembly Department. The Glass Department, for example, developed and installed a large part of its own glass-making equipment. It begins its process with the sand, potash, and other necessary ingredients and produces the glass envelopes for most of the lamps produced by the Division. The wide variety of types and sizes of lamps requires an almost equally wide variety of types of glass.

Despite the growth of the business there were various disturbing signs that appeared during and immediately after World War II. Although the business had grown rapidly, the rest of the General Electric Company had grown faster and the rest of the electrical industry had as well. There were strong indications of the possibility of loss of market position to the very strong competitive forces that had grown up around the Division. Why was this happening? Was it due to a lack of direction, a lack of long-range planning, or the fact that the business had become too diverse to be managed effectively under the organization structure which had been in place for over 25 years?

These were the questions and the problems that faced the Lamp Division. In late 1952 it was decided to conduct a broad study of the Division in order to determine the nature of its strengths and weaknesses and to make recommendations for the future conduct of the business.

In the spring of 1953 a task force was organized to make this study on the basis of which it was (1) to recommend the operating objectives of the division for the next five years and (2) to recommend the type of organizational structure best suited to the attainment of these objectives and the long-range growth and health of the business. The members of this task force were selected from within the Division. Each of the members had worked in the Division for a number of years and brought to the task force experience from every aspect of the Division's activity. The task force was headed by a member of the Vice President's administrative staff. He had previously worked in the marketing and financial areas. The other members were the home office manager in charge of sales districts who had previously been a district sales manager, the home office manager in charge of lamp assembly who had previously been a plant manager, the home office manager of the Division's distribution network who had previously managed a district warehouse, the manager of the Division's chemical plant, the manager of one of the glass plants, the manager of the manufacturing development program, the head patent counsel, and the head of the auditing staff.

In the opinion of top management, the nine members of the task force could adequately represent all of the important functions of the business. The organization of the group and its purposes was broadly announced to all key personnel in the Division and their cooperation in helping the task force accomplish its objectives was solicited.

It was brought to the attention of these key personnel that the purpose of the task force was to help the Division to keep growing, to grow at a faster rate, and to buttress the areas which had weakened. Conversely, the task force was not a Gestapo or an efficiency team bent on lopping heads, in order to gain current dollars.

The broad announcement of the charter and plans for the task force and the request for cooperation proved an invaluable aid during the study. It not only made available to the task force valuable pools of knowledge and experience, but it allayed the fears of drastic personnel shakeup and allowed the Division to continue to operate at a high level of efficiency without fear of personal insecurity.

The administrative member of the task force and the auditor began to work on the problem full time. They met with the other members of the task force on a two-day-a-week schedule. This soon grew to 3 days a week and, in the final stages of the project, eight days a week.

The task force began its work with a comprehensive self-orientation program. A brief inventory, history, and summary of the operations of each organizational component was prepared. These studies were designed to disclose the purpose of the unit, the range of products involved, the volume of products handled, and the investment in the plant and personnel. The units considered included not only production and sales units but satellite units in purchasing and finance, and even the groundkeepers at Nela Part where Division headquarters are located.

Next the group began to list the things it felt it ought to know to discharge its charter. Paper began to accumulate. The task force was soon up to its hips in paper. It became apparent that in order to avoid winding up floundering in a sea of data some research plan was necessary. Several of the members of the task force had been following the development of O.R. with interest and their problem presented them with an opportunity to try it out.

The task force discussed the possibility of using O.R. with the Operations Research Group at Case Institute of Technology. It arranged to have one of this research group's members serve in a consulting capacity. In a short time this consultation developed into full-time participation of three members of Case's group.

ANALYSIS OF THE PROBLEM

This study done by the supplemented task force was not a typical Operations Research Project. It differs from most in subject matter and scope of its problem, in the methods employed, and in the organization of the research effort. But the project very effectively illustrates the flexibility of the O. R. approach and it points up its as-yet-unused potential.

The "atypicality" of this study is reflected in the way the year's research time was allocated to phases of the project. The first seven months were spent in formulating the problem, the next two in designing the data collection and analysis, and the remaining three in the actual collection

and analysis of the data and in preparation of the final report. A second atypical aspect of this study lies in the fact that a mathematical model did not play a central role because of the complexity of the system and the limitations of time. The problem had too many variables to represent and manipulate in mathematical form. However, the same kind of thinking that goes into the construction of such models was used to develop a conceptual model which was used throughout the study. The lack of an explicit mathematical model did not prevent the study from being formulated and conducted in quantitative terms.

The instruction initially given to the task force was essentially "to develop a five year plan for the Lamp Division". The first job undertaken by the supplemented task force, then, was to determine what a five year plan should contain. The group began by blocking out the major areas to be covered. It seemed clear that the plan should (as stated in the task force's charter) establish objectives for the Division; that is, goals the Division ought to attain. It also seemed clear that the means (operating policies) for attaining these objectives would have to be specified. Next, the additional resources required to carry out these policies would have to be determined. Then the task force realized that the effective use of resources and the maximum exploitation of policies depends on the organization involved. Consequently, it was decided the five year plan should also contain a set of organizational specifications covering the structure (or form) and the functioning (method of operation) of the organization so that the most could be gotten out of the policies established and resources provided.

The five-year plan, then, was to cover the following major areas:

(1) Specification of objectives for the next five years.

(2) Specification of operating policies by which the objectives could best be obtained.

(3) Specification of the resources required to carry out the policies.

(4) Specification of the structure of an organization best suited to carry out the policies with the resources specified.

Unfortunately, one can't look at any of these four problems separately. What goals one can reasonably expect to attain depends on the resources which are available, but specification of required resources depends on what one can expect to attain with them. Furthermore, the best type of organization obviously depends on what operating policies are specified. But one can't select these policies without an eye on the kind of organization one is going to have. The major methodological difficulties in conducting this study arose from the fact that each one of the four aspects of a five-year plan had to be studied in such a way as to know what to do regardless of what the answers found in the other areas would be.

For example, there were essentially three major types of organizational structures considered. Objectives, operating policies, and resources had to be established for each of these three different types of organization because it was only when all the information had been gathered and analyzed that the task force could find that particular combination of objectives and organizational structure which would (in some sense) yield some approximation to an optimum five-year plan.

SPECIFICATION OF OBJECTIVES

In setting organizational objectives it was recognized that it would be trivial and futile to state such objectives as "an increase in profit", or "an increase in sales", or "product leadership". Such invocations have no operational value to a business. They cannot meaningfully direct action; they are much too general and ambiguous. How can a statement of objectives be made operationally meaningful? It was to this question that the task force addressed itself.

Two things were relatively apparent: (1) The objectives had to be formulated separately for each of the five years so as to indicate a desired rate of improvement during the period and (2) they had to be set for each major functional area of the business: marketing, manufacturing, and engineering (which included the research and development function). If, however, one were to set a marketing objective as "to increase gross sales by 10% next year", this statement would still not be very meaningful in an operational sense. For example, does it mean that gross sales of every product should be increased by 10%? Obviously not. Then what does it mean relative to different products? This question could not feasibly be answered since the Division markets more than 15,000 product types. Hence some classification of products into product lines was required.

How should the products be classified? For the marketing function they should be classified in terms of common characteristics of sale, distribution, and consumption. But such a classification would not be pertinent to the manufacturing and engineering functions. Products with the same marketing characteristics may have different manufacturing and engineering characteristics. For example, the large incandescent and fluorescent lamps have common marketing characteristics but do not have common manufacturing or engineering characteristics. The problem of classification, then, had to be accomplished in two stages: (1) classify products relative to each of the major functions of the business and (2) find the smallest number of basic classes out of which the classes in the first stage could be formed. This analysis yielded 37 (exclusive and exhaustive) product classes under which each product could be listed. From these, for example, 11 product lines were formulated for use in setting marketing objectives.

Objectives, then, were to be set for each year for each product class. Now, specifically what should be the nature of the objectives? It is not enough to set profit objectives because these are too general. It was decided that profit must be broken down into its components: income and costs. Income means sales volume and costs reflect the productivity of each operating, service, and administrative function.

In an expanding market a company can increase its sales volume and still lose market position. Therefore it was decided to set objectives for each product class in terms of share of the consumer's dollar based on forecasts of the number of consumers. A fourth class of objectives involving productivity was to be taken care of by specifying operating policies, resources, and organizational modifications, if any.

SPECIFICATION OF ALTERNATIVE OPERATING POLICIES

The next job was to specify the possible ways of increasing sales volume beyond what would be expected if then current policies were continued. For example, the sales and distribution operations were thoroughly analyzed and about 50 possible types of policies were enumerated for lamps. These were of the following types:

1. Price changes.

2. Additions to and deletions from the product line.

3. Changes in consumers utilization of light sources.

4. Increased expenditures in such things as advertising, sales promotions, research and development, and packaging of products.

5. Changes in channels of distribution.

6. Changes in arrangements with wholesalers and retailers.

Corresponding alternatives were enumerated for lamp--manufacturing equipment and lamp components.

SPECIFICATION OF RESOURCES

Expansion of the question concerning additional resources was relatively straight-forward. It involved determination of requirements or people, space, equipment, and so on for each operating and administrative unit. This portion of the study was "farmed out" to a group which was organized for this purpose by one of the members of the task force. The existence of good records made it possible to determine quite accurately the amount of resources required in operating units for various levels of activities.

SPECIFICATION OF ORGANIZATIONAL STRUCTURE

Amplification of the organizational aspects of the study were by far the most difficult. Here opinions throughout the Division, though differing, were most positive. Preconceptions in the task force had to be carefully set aside to get at these problems in a basic and unbiased way.

In the area of organizational structure the following questions were designated as requiring coverage by the Five Year Plan:

(1) The optimum size of operating units (in each function).

(2) The optimum number of similar operating units to be coordinated by one manager.

(3) The optimum basis for coordinating units (e.g., geography, function, or product).

(4) Given a basis for combining units, the optimum combination of existing units.

The approach taken to these questions consisted of breaking operations down to basic functions and operations which are individible from a supervisory point of view. The question then was how should these be combined for management. The approach was to start combining units and functions from the bottom up. Once the first level of coordination was determined, then the second could be, and so on. This approach would reveal the optimum number and location of levels of management. In addition it would allow use of different principles of coordination in different parts of the organization. This is, this approach allowed for the possibility of coordinating some operating units by product class, others by function, and still others by a combination of these. In this way, it became possible to consider types of organizational structure other than the purely product-department or functional-department type. The final recommendations, as will be seen, involved a mixture of coordinating principles.

SPECIFICATION OF ORGANIZATIONAL OPERATIONS

The purpose of organization is to gain or maintain control over a complex system of interconnected activities. Control means efficient direction toward objectives. To understand organizational functioning, "control" had to be analyzed. At this point discussions in the task force became theoretical and philosophical. Basic concepts in servo-mechanism and decision theory were being explored. As a result of these discussions, the control function was divided into the following steps:

(1) Initiating recommendations for change: a question of responsibility (an administrative function).

(2) Accepting or rejecting recommendations: a question of authority (a legislative function).

(3) Carrying out decisions: a question of responsibility (also an administrative function).

(4) Evaluating the policies or courses of action in operation: a question of responsibility (a judiciary function).

These steps constitute a cycle since out of evaluation comes recommendations. The generality of these steps and their pertinence to other areas such as politics is apparent.

The first question concerning these phases of the decision-making and control process is: Who shall perform them? The "who" does not call for one or more individuals by name, but by function; for example, the unit manager, the coordinating manager, the administrative manager, the general manager. The second question involves the organization of those involved into a decision-making and control procedure. These procedures are sequential in time, so the order of the steps must be specified.

Once those who should be involved in a decision are specified, their role must be specified. For example, if the first manager in the sequence approves a recommendation, is any further approval necessary? Or, if he disapproves is this the end of the matter or does it go on? Analysis showed that each of the possible decision-making organizations could be specified by answering three questions:

(1) Whose approval or disapproval is to be solicited and in what order?

(2) Whose approval is necessary for initiating action?

(3) Whose approval is sufficient for initiating action?

The answer to these questions depends on the organizational structure, in particular the number of management levels and the scope of each level. Since the task force did not know what organizational structure would be revealed as best by the study, the question concerning decision-making would have to be explored for each type of organizational structure.

Obviously the same decision-making organization cannot apply with equal efficiency to all types of decisions. It was not feasible, however, to consider all possible decisions that require management attention. Consequently, some classification of potential management decisions had to be provided. The previous analysis of the parts of the five-year plan provided a basis for such a classification. The resulting classification was as follows:

(1) Matters affecting the organizational status and stature of all managers.

(2) Matters pertaining to the organization and operation of an operating unit.

(3) Authority and responsibility of Home Office Service Units on matters affecting Operating Units and Coordinating Units.

(4) Matters pertaining to Lamp Products which involve more than one function (i.e., marketing, manufacturing, and engineering).

(5) Matters pertaining to Lamp Components which involve one or more functions devoted to finished lamps as well as component organizational units.

In each one of these categories a further breakdown was obtained along a scale of importance. The scale of importance was defined by use of three criteria: (1) the amount of money involved in the decision, (2) the number of organizational units affected by the decision, and (3) the duration of the effect.

DESIGN OF DATA CORRECTION AND ANALYSIS

The second stage of the project, which took approximately three months and which can only be touched lightly in a report of this kind, involves the design of the data collection and analysis. Essentially there were three kinds of data collection procedures developed. First, the task force had to estimate what would happen if the Division operated with no changes. In order to evaluate any proposed plan of change it was necessary to compare the estimated outcome of the proposal with estimates of what would happen if no changes were made.

Fortunately, the Division's Marketing Research Department is one of the best known in the country. Its director is one of the most competent people in the field. There was no reason to expect that anybody at Case or in the task force could do a better job than this group in determining where the business was going for each of the next five years if nothing was done. Consequently, this forecasting was turned over to the marketing research staff and they prepared a set of estimates which became a base from which the task force operated. These estimates were checked by all managers in the marketing department. Where there were large discrepancies of opinion based on more than feeling, a careful investigation was conducted and necessary adjustments in the estimates were made. For example, some of the field marketing people knew of specific competitive developments which might effect future sales volume. These were studied and in at least one case and adjustment in the forecast was required.

It might also be mentioned that the forecasting of the marketing managers was checked by asking them to estimate business in a past period, figures on which were not yet available to them but which were available to the task force.

Secondly, as already indicated, information on resources including the cost of acquiring resources required at various levels of business operation was turned over to a special group and that material was being accumulated while the rest of the problem was being formulated.

Finally there was a considerable number of questions that had to be answered which, if they were to be answered by the best methods that were known, would probably have taken about ten years. This is not an exaggeration. Consequently, the problem was how the task force could in a relatively short period of time get any meaningful data on effectiveness of operating policies, organizational structure, etc. It was apparent that the task force had to resort to a questionnaire. A questionnaire would have to be used to get information from informed sources, information which would provide the basis for evaluating alternatives. The task force was well aware of the danger of the use of the questionnaire.

The criteria that were used in the construction of this questionnaire were as follows: (If these look simple-minded and obvious, an effort to construct a questionnaire that would satisfy these conditions will prove the contrary.)

First of all, the questionnaire was to include no question the answer to which would have no effect on the recommendations. The task force insisted on being able to demonstrate how each set of answers would be used before the question was included. Explicit instructions for the use of the answers of each question were prepared in advance. This involved consideration of each possible set of answers that the question could receive and what these answers would imply with regard to the ultimate recommendations.

Secondly, the questions had to be questions of fact, rather than questions of attitude. No one was to be asked such a question as, "Do you think it's better to organize units on the basis of product similarity or functional similarity?" The respondent must be given a criterion of measurement for each question and his answer was to be based on knowledge or an estimate of this measure.

Thirdly, every question had to be in such a form that the answers to it could be subjected to quantitative analysis. This would provide measures of the reliability of the answers; that is, an ability to determine if there was consistency among the respondents to the questionnaire. Furthermore, by designing redundancy into the questionnaire a check on the reliability of individual subjects was obtained.

Another problem was how to be sure that any preconceptions possessed by members of the task force were not included in the questionnaire. Initially, the task force was relatively homogeneous in what it thought its ultimate recommendations were going to be, but considerable differences of opinions developed among its members as to what the ultimate recommendations would be. The objectivity of the questionnaire was checked by giving it to a number of the members of Case's O.R. Group, individuals who had not been involved in this study in any way. They were explained the underlying structure of the questionnaire and they were told the task force had decided what the objectives were going to be, what policies were going to be used, what the organizational structure was going to be and what the decision-making procedure was going to be. They were to study the questionnaire and to determine from it what the recommendations were going to be. Not one of the receivers of the questionnaire was able to formulate any consistent concept of a bias in the questionnaire. The task force then felt relatively sure that there were no leading questions. The results certainly supported this belief because in most areas the results obtained were completely different from those that had been anticipated in the early stages of the project.

As this questionnaire was being prepared, not only was the procedure for analyzing each item being worked out, but the forms on which the results would be tabulated were also completely prepared. The clerks were trained for the tabulation of the results while the questionnaire was in the hands of the respondents.

Although there were over 500 questions in this questionnaire, only one question yielded unusable answers. This one question turned out to be ambiguous.

ADMINISTRATION OF THE QUESTIONNAIRE

The task force now felt that it had within its grasp the tools that would provide the answers that were needed to

develop a five-year plan. A list of the key members of the division whose opinions would be solicited was prepared. The questionnaire was printed, bound, and made ready to go. Here the task force anticipated a danger. If this cold, imposing three inch questionnaire was sent out without any preconditioning or explanation, it could be a colossal flop. Arrangements were therefore made for members of the task force to meet with the intended respondents. The task force organized itself into teams of two and started on the "wear tux, willing to travel" circuit. These teams met with the intended respondents in centrally located cities throughout the country. They met with not more than 5 of the 168 respondents at one time. The meetings lasted for a full day and usually ran far into the night. The meetings were opened with a review of the purpose and the charter of the task force and what it was trying to do. Reasons were given for soliciting the opinions of the intended respondents. The questionnaire was reviewed, page by page, question by question. Every point was reviewed to make sure that the questions were completely understood and the respondents were asked to make any notes that they cared to on their copy of the questionnaire which was presented to them during this meeting.

The measuring and intention of each question was discussed. For example, one question asked the respondent to suppose that the then current Glass Department was to be divided into three parts. He was asked how he would assign the various products--there were approximately 50 of them--into these three preconceived product departments? It was made very clear to the respondents that the question was designed to explore the homogeneity of the products being manufactured and in no way did an answer to this question constitute an endorsement by the respondent of product departments.

Such care was taken because there was a great deal of native pride and loyalty to the Division as it had been constituted. In light of this strong feeling it would not have been wise merely to ask, "How could you group the glass products into three product departments?" Only by properly motivating the respondents could information be obtained which could be used to determine which were the homogeneous products from different points of view--the engineering, marketing, manufacturing, warehousing, shipping, etc.

Each of the intended respondents was given a complete questionnaire. Some of the questions were on subjects

concerning which any one respondent had virtually no knowledge. But each one was given the opportunity to answer every question. He was also free not to answer any question if he felt he was not competent to give an informed answer.

The respondents were given one month to fill in the questionnaire. The average time spent on the questionnaire was about 48 hours. These respondents had other jobs; they were sales district managers, engineers. They continued to operate the business on a day-to-day basis. In addition, they were encouraged to consult anyone they cared to. It was emphasized that the questions sought information, not votes. In some cases respondents worked together in preparing their answers, but even in these cases the answers were not completely similar.

While waiting for the questionnaire to be returned, the task force continued to work. It did such things as visit the Division's allied industries, industries whose future activity would affect the Division's business.

The completed questionnaires were eventually received. Collation and tabulation were begun. A pretrained group of about eight checked answers for their reliability.

The data obtained were used as a basis for specifying objectives, operating policies, and resource requirements for each function of the business relative to each product line. This was done as follows. Various combinations of sales volume, quality level, productivity level, and rate of product innovation were examined to determine the profit associated with each combination over the five year period. The profit was estimated by subtracting from the associated forecasted sales volumes, the appropriate operating costs, and capital expenditures. Determination of the appropriate operating costs and capital expenditures in turn required determining which combination of operating policies would yield the specified sales volume, etc., at minimum cost. That combination of sales volume, quality, productivity, and innovation objectives which yielded the greatest expected profit was selected for each product line.

Once this had been done for each product line the requirements for additional resources for each product line were brought together and an over-all plan for expansion of resources was developed. This analysis showed, for example, that even if all plants were operated at 100% capacity they could not produce the volume of products

forecasted if the new policies were used. The need for immediate expansion of facilities, which had not been previously appreciated, was clearly established. Details for this expansion were drawn up.

The data obtained were then used to determine what organizational structure would yield the highest probability of attaining the specified objectives with the specified operating policies and resources. This was done by starting with the operating elements of the organization and determining from the data obtained how best to combine these elements for control purposes. This procedure was carried out to successively higher organizational levels.

The data obtained indicated that the principal shortcoming of the existing organization was its sluggishness in responding to changes in the market due to competition, consumers, or other sources. An organization had to be developed which could quickly adjust itself to changing conditions. The business of the Division had outgrown the existing organizational structure. Decisions could not be made as rapidly as was required. Perhaps, most important, decisions were being made at too general a level. For example, decisions affecting the marketing all products tended to be made in terms of the highest-volume product line, so-called "large lamps". Such a decision, although good for the large-lamp business, was frequently harmful, for example for the photo-lamp business. The attempt to remedy this situation is reflected in the organizational structure which this analysis revealed as the best.

The organization structure recommended consisted of six product departments and three contributing departments. Each of the six product departments was to be a self sufficient organization and could be a business in itself, were it not within the G.E. structure. Each had a sales volume sufficient to realize a profit adequate to maintain a complete organization of engineering, finance, etc. Each had growth potential and each would have the responsibility for engineering, manufacturing, marketing, finance, and employee relations. These six product departments were constructed so that no product department infringed to any major degree upon the responsibilities of any other product department. They were businesses within themselves.

The major portion of the income of the division comes from the sale of finished lamps through regular commercial channels. Three finished lamp product departments were recommended. First, a large-lamp product department was recommended, a department which would produce and market the kinds of lamps most frequently seen in houses, office buildings, stores, etc. The second department was to be responsible for miniature lamp products which include lamps which operate off of a portable power unit such as those used in automobiles, flashlights, aeroplanes, etc. The third department was responsible for photo lamps which are primarily used for photographic purposes.

Three parts departments were also established. The Glass Department, Lamp Wire and Phosphors Department, Lamp Leads and Bases Department. These three departments are to be responsible for manufacturing most of the components that are used by the three product departments.

In addition, three "contributing" departments were recommended: an Advanced Lamp Development Laboratory; the Legal Department; and a Lamp Equipment Operation. Each of these operations is very costly and the talents and investments in each could not feasibly be reproduced for each of the product departments. The uniformity of approach and interpretation in the free exchange of knowledge which is required could better be obtained on a divisional basis rather than within each of the departments.

The over-all recommendations were submitted to the Division's general manager in October, 1954. Minor modifications were made by him and corporate management.

On January 5th, 1955, the new organization structure, and the 1958 objectives were announced to the Division's key personnel at a management meeting. The year 1955 was spent re-organizing in accordance with the task force's recommendations.

Some lamp plants were producing products falling into two or three of the new finished product departments. These manufacturing activities have to be reallocated to appropriate plants so as to have each plant providing for only one department. This reallocation is now about 80% complete.

It is too early to evaluate completely the study reported here. Yet certain consequences of the adoption of the plan are clear and impressive. The product department marketing groups have shown an increased responsiveness to the needs of the trade. The same is true of the manufacturing and engineering groups.

The objectives set for the first of the five years were met and in some cases surpassed. These and other indications to date are all favorable.

The apparent success of the study "sold" the Division on O. R. O. R. has been used extensively since. Among other studies completed since the one reported on here, is one on the allocation of sales effort.

In the Photo Lamp Department an operation research group has been set up and is studying over-all departmental problems. It is currently working with the Case O.R. group in formulating a long range management research program for the department.

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SKILLS REQUIRED FOR APPLICATION OF AUTOMATIC DATA PROCESSING SYSTEMS

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NOTE: - It is regretted sincerely that there is no manuscript for this particularly fine presentation. - Editor

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SYSTEM SIMULATION

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BACKGROUND

The Industrial Engineering Department of United Air Lines has, since 1940, served as an internal consulting group. The department reports to a Vice President of Economic Controls who also heads such functions as Economic Forecasting, Market Research, Airplane Schedules, and Cost Control. Our concept of the industrial engineering function is extremely broad, and included within the department are four divisions - Work Analysis, Organization Planning, Regulations and Forms, and Operations Research and Applied Science.

In 1954 we became interested in Operations Research. After attending several seminars and talking to consultants and people who were doing work in the area, we tried to analyze what was new to us about the concept, approach and techniques involved. As you can see by the following, we were less impressed with the techniques and complex formulas as with the new concepts which jarred us out of old ways of thinking and brought new meaning to the scientific approach to management problems and decision making. The results of this analysis in very simple terms are as follows:

1. Increased emphasis on first understanding the facts of life and trying to determine if a pattern exists. Unlike scientists, engineers and business men are usually problem orientated; too busy solving problems and putting out fires to step back and try to understand or relate underlying causes.

2. Increased emphasis on looking at the whole rather than the bits and pieces which on the surface are causing all the trouble. For many this means lifting those departmental curtains which fence them in and prevent an over-all look or system approach.

3. Seek out and apply knowledge from seemingly unrelated areas and bodies of knowledge. This includes the assigning of men from other fields of endeavor to work on projects and relate the techniques, concepts and patterns found in other sciences to the problems facing us.

4. Increased emphasis on measurement in quantitative terms. The human factors and intangibles in our work may in the past have caused us to become satisfied too easily in our search for basic measurements and in identifying those things which must be measured.

5. Introduction of the concept of variation, probability and the interaction of variables. This usually represents a basic change in thinking since most of us as a result of our training and experience are prone to think in terms of averages and empirical values. These concepts also change one's whole approach to the problem of measurement.

6. The use of mathematical and statistical tools, some of them which have been around for a long time and others which have appeared under such names as linear programming, queueing line theory, etc.

7. The concept that a model can be developed to represent or simulate a given system or operation. This is probably the most important of the new concepts and is often the culmination of the previous six. It is this concept that we would like to briefly discuss.

THE NEED

The word "model" is not new to the various branches of engineering. It has been applied to working proto-types, plant layouts, laboratory setups, wind tunnels, etc., but to our knowledge the concept of a model which will simulate an entire system representing the interaction of men, machines and materials is new. We talk about scientific management, yet management does not have the means (available in most other sciences) to test, compare, and evaluate ideas except by actual trial which in many cases is practically impossible or economically unfeasible. To a business man the physical sciences often appear quite complex, yet what is more complex than a modern industrial enterprise.

Models of business operations which do exist at present are extremely limited. The organization chart is a static model which in reality means very little. Process or flow charts, in many cases, represent a static situation, while the accounting model, one of the oldest, is mostly historical. It attempts to keep score and price out according to current concepts some of the costs involved. The very complexity of the production process alone in most industries today simply demands the development of a means to simulate parts of the whole operation. Management has a right to expect a method or a tool that will enable them to test their ideas and various alternatives so that they may have a better basis for making decisions and calculating the risks involved.

THE CONCEPT

Once one becomes aware of the fact that the variation in a system can be measured, the probability of occurrence determined, and the existence of certain patterns realized, the method of simulating systems

becomes apparent. The measurement of the variable factors in an operation must be approached in a practical manner. First of all we must face up to the fact that we must measure life as it is and in a way that it can be measured. We can't wait for the social scientists to completely figure out the human being. Although we may be far from measuring detail causes and why people do certain things, we certainly can at this time measure what they do and face up to those facts in any given situation. Many of our headaches are caused by idealizing each situation and not recognizing the facts that are staring us in the face and the interaction of the variables involved. There will be those who say that you can't measure certain intangibles or judgment areas, but here, too, we can take a practical approach and get together with management to at least assign values which will be acceptable to them and consistent with their objectives.

THE METHOD

In some cases an operation can be completely represented by a mathematical model; however, we have found that in a complex business operation a straightforward logical model must often be used. Once the pattern in an operation is determined, the key variables along it measured, their probability and relationships determined, and the logical or decision rules developed, all the means are present to simulate the system, utilizing what has been called the Monte Carlo method. Those things which happen in life in a random fashion can be simulated by coding their probability of occurrence and then drawing random numbers from a table or computer to breathe life back into them. Where definite relationships exist, they can be stated. Due to the complexity of many problems, an electronic computer is the only practical device that will follow the necessary logic, handle the large volume of repetitive steps, and combine the various probabilities so that the resultant interaction can be determined. Once a model has shown that it simulates life it can be used to test various ideas or plans by varying one item of the input to determine the effect on various outputs which the model has been asked to produce. There are, of course, limitations and great judgment must be exercised in the development and use of the model.

Probably the best way to illustrate this concept of system simulation is to briefly tell you about a project we have been working on.

THE PROJECT

In July 1954 we decided to undertake a full-blown operations research approach to our system aircraft routing and maintenance problem. We had been told to start off on a small problem; however, we decided to tackle one of the most complex ones in the whole company. Our management, with a great deal of vision, agreed to underwrite this project with very little promise of what might be their return. As members of the research team we picked Mr. Stan Nowlan, our Superintendent of Flight Operations Engineering, who is a top-notch aerodynamist with an excellent

background in higher mathematics. He was from our San Francisco Engineering Department. Then, a 25 year veteran in the Flight Operations field, Mr. Tom Plunkett, from our System Flight Dispatch Manager's group at our Denver Operating Base. Recognizing the importance of statistical techniques, we assigned our Staff Superintendent - Quality Control, Mr. Win Dalleck, and in addition, an Industrial Engineer, Mr. John Porter, who had a good deal of experience working on system problems.

The project involved a basic study of the whole process of providing serviceable aircraft to meet schedules over our 14,000 mile system. Our first objective was to determine and analyze the true nature of that operation and measure the variables which existed. The second was to develop a means or a model which could be used to test the effect of changes in policy, maintenance concept, schedules, facilities, and manpower. It is important here to note that we started out to do research and to first understand, not to formulate or study, a particular problem. We didn't want to sub-optimize, as it is generally termed, or to force any part of the operation into a particular form through use of a certain technique.

APPROACH

As is our practice, a detailed approach was prepared and the project started with the team interviewing over 100 people who were directly concerned with the aircraft routing and line maintenance functions. With this background the team proceeded to evaluate all existing data. In applying basic questions to the operation and following them through to the point where data needs were defined, it was found that practically none of the data needed was available or in the desired form. This experience will, we feel, be duplicated in many industries and points up how little data is being gathered today which really measures an operation and enables management to manage versus that required to satisfy legal, accounting, government agency, and staff needs.

To obtain the necessary data, three special forms were designed and field people briefed in their preparation. Over four months' data was then collected from our major service stations and checked for bias.

As the study progressed, it soon became apparent that the key to our system lay within each major service station. It also was obvious that a definite flow or work process existed at each station and we made sure that the variability, nature and probability of key factors at each significant point along that flow was measured.

For example, our Flight Schedule represents the schedule input and output to a station but we knew that the actual arrival times varied. So as a result we came up with a variability table which showed the full range of deviation from schedule; in other words, the probability of an aircraft arriving 20 minutes late, 30 minutes early, etc. This

chart, although a simple one, was in reality a realistic measure of our entire operation as our customers see it.

We went on to determine the probability of the different types of maintenance work that would have to be done on an arrival, and the variation in the different types of work that would be required, both what we call routine and non-routine work. We even measured the variation in the number of men actually available to work from those on the payroll.

It soon became apparent that, as a result of the station flow and our measurement of it, we had all we needed to construct a model that would simulate an entire station operation. We wound up Phase I in June of 1955 and presented the findings in a two-hour illustrated presentation to 200 of our management and field people.

Phase II, or detailing the logic of the station model, was completed in January and turned over to IBM's service bureau for programming on their new 704 computer in New York.

Although we tried to use mathematical techniques, we found that our problem was best simulated by the Monte Carlo method using random numbers to breathelife into the actual probabilities we had gathered from our stations. In working with IBM we find that we have tackled probably one of the biggest problems of simulation that they have run up against. The risk is great but the potential of the model as a management tool is tremendous.

The station model as it will be set up on the 704 computer will enable us to simulate several months of actual operation, say, at a station like Newark, in a matter of minutes. By varying the input of such items as manpower, facilities, schedule or maintenance policies, we hope to compare outputs and get an indication as to the best course of action. As output the model will give us such things as idle manpower, utilization of maintenance docks, schedule delays, maintenance working and waiting time, etc. Management has numerous questions to ask this model which, with the substitution of the proper data, is good for any one of our stations.

Without even operating the model, we have found, for example, that we can take portions of our data and combining probabilities by hand, determine information vital to our operation.

A CHALLENGE

If a science of managing is ever to emerge, a way must be found to better predict the consequences of changes in our industrial system. Managers are finding the trial and error method too expensive and

are looking for a means to test their ideas, calculate risks and predict results. Models which dynamically simulate integrated systems of men, machines and materials can help satisfy these needs. The concept, the method, and the means are available. It is up to men of imagination and perseverence to apply and shape this tool. System simulation may well represent the next significant step forward in scientific management.

IMPLICATIONS OF CURRENT DEVELOPMENT TRENDS

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As the luncheon speaker said, since all the mistakes in the introduction were in my favor, I will not attempt to correct them -- with one exception. In the presence of such a famous pioneer as Prof. Aiken, I can't let go unchallenged the statement that ours was the first data processing machine. We were decidedly late comers in comparison to the pioneer work of Prof. Aiken. We were very happy, however, to be the first of the group in the headlong rush after the war to get an all-electronic system into productive operation.

In speaking to a group of industrial engineers, I think I can sense a community of interest in the fact that the modern data processing equipment, now moving into office activities and soon to move into the industrial control activities, has many items in common with respect to manner of thinking. To do an effective job in the processing of the information on the paper that flows through an office requires an analysis and a point of view not far different from that which the industrial engineer applies to the design of processing systems for material things. It has only been a short number of years that we have had the tools and the attitudes that led us to talk about mass production of information in somewhat the same sense as we talk about mass production of material items. Because of these similarities, I think that this is a particularly fruitful field for men with industrial engineering training to interest themselves.

My topic, "The Implications of Current Development Trends", sounds quite specific. I am going to take a few liberties and be rather general in my interpretation of these development trends. I will start by pointing out that we are just emerging from a period that was characterized by a determined effort to make better use of what we have. Until now the computer design engineers have depended heavily upon technical borrowings from the electronics of the communication and the entertainment fields, and they have done an amazingly good job of devising usable equipment out of elements that were not developed for a such purpose.

An important question that worried many of us during the early development days was whether there was adequate reliability inherent in the components from which we were attempting to build these digital computers. Almost everywhere you turned there was lack of adequate information about those reliability characteristics which were going to be controlling ones in the success of the computing assemblies being planned. Just how reliable need they be? To avoid going into this topic in detail, let me use a crude analogy to explain why this caused such concern: Imagine that you were designing television sets with a marketing agreement that said that for every 500 television sets delivered the failure of any one in the lot to perform was adequate justification to return all of them. This is approximately the level of reliability that holds for the design of an assembly of electronics sufficient to serve the functions of an electronic data processor; one must work toward a level of over-all reliability that would correspond to requiring that either all 500 television sets function concurrently or else none of them would be acceptable.

It was somewhat unexpected that the available electronic techniques and components could be readily adapted to this level of reliability for the task. A combination of careful design and intelligent schemes for maintenance and operation have resulted in truly remarkable performance records for a number of the more recent computer installations. There are reported productive operating figures, stated as a percentage of scheduled time, consistently above 80 percent, and often well above 90 percent. Even where "around-the-clock" scheduling has been required to handle peak work loads, with only emergency maintenance permitted, productive operating percentages of better than 70 percent of the 168 hours in the week have been achieved.

Even after making reasonable allowance for excessive pride of accomplishment, these are gratifyingly fine performance reports from the equipment that resulted from the first round of electronic computer development. This provides a substantial basis of accomplishment from which to proceed. I am going to defer discussing the topic of the new technology that is being created by simply pointing out that we now are beginning to design with components and devices that have been developed with the reliability considerations of the computer field specifically in mind.

Let us consider again this matter of making fuller use of what is now available. This applies with particular force to the application of computer technology to areas outside that of scientific and engineering

calculations. Where these applications pertain to the mechanization of office and factory-type paper work, the generic term of data processing has been applied. Most of the machine features needed to carry out calculations are needed for data processing tasks. However, data processing activities call for a shift in relative emphasis from calculating power only to the expeditious handling and storing of large volumes of data. This shift in emphasis tends to manifest itself in the appearance of a variety of terminal equipment that has been added to the central computer. In addition, peripheral equipment is needed for the transcription of a variety of forms of source data for entry into the machine and the subsequent transcription of the processed data. Because most of these devices have been added to a central computing facility, only recently has serious consideration been given to organizing the central facility to provide a more effective over-all system of processor, terminal equipment, and peripheral equipment.

One of the most important terminal equipments attached to the computer has been the magnetic tape units that are controllable from within the computer through its internal program of instructions. The magnetic tape units have provided an effective means by which rapid transfer of large volumes of data can be attained between the inside of the computer and the outside world. The high data transfer rates made possible through the use of these "scroll" type magnetic files have opened the way for the mechanization of a number of office and factory paper work procedures. However, the information that appears on these magnetic tapes cannot be sensed directly. For this reason, specialized means are needed to transfer the source information from the outside world and deliver back to it the processed information. To this end a group of both peripheral equipment and specialized terminal equipment have appeared in order to take advantage of the exceptional performance of the magnetic tape units.

The most dramatic of these peripheral units are the new high-speed printers. These have attained surprisingly high levels of performance -- of the order of ten lines of printing per second and still higher performance is in immediate prospect. The outpouring of information in one second represented by ten lines of printing, each having as many as 100 characters, leads one to reconsider the role of the printed record in office transactions. We need to ask ourselves the question: Is anyone really going to read all of the material we now can print? Clearly, there are instances in which plenty of people are available

to help read this printed material. As an example, the task of examining the printed output, if it represents electric utilities bills or insurance premium notices, is well distributed among many people. On the other hand, there are instances where there is a tendency to pile up reams of papers simply in anticipation that somebody might need to examine the record. With the ability to have the pertinent items selected from the magnetic tape files at the time it is needed, one could plan to restrict the amount of printing to the specific items that are needed. Clearly, one must determine whether the cost of converting from magnetic file to printed records serves a useful purpose in the light of these new capabilities.

The high-speed printer is a peripheral device that has a direct purpose. In contrast, there are comparatively elaborate peripheral devices that only serve an intermediate purpose. Specific examples are the devices used to convert previously punched cards to magnetic tape and the devices for transferring the completed information on the magnetic tape to punched cards. These two devices have been selected for discussion because they represent examples of the growing pains associated with making the most of available equipment. There are ample sources of punched card producing equipment and trained operators for their use. Therefore, there is temporary justification for utilizing these resources and bridging over to the data processing installations through the card-to-tape converter. In addition, we may wish to operate the electronic system in conjunction with punched-card installations already in operation. Thus, we must transfer the information on the magnetic tapes to punched cards for subsequent use.

These intermediate steps are new potential sources for error and introduce nontrivial additions to the operating costs. The card-to-tape and tape-to-card converters, like the high-speed printers, are peripheral equipments that are currently priced in the range of $150,000 or higher. It is unfortunate that the information cannot conveniently be created in the proper form at the outset so that the data processor can use it directly. Developments of this sort are under way, but at the moment we must use these peripheral equipments in our effort to make effective use of what we now have at hand.

Another area in which we presently must improvise is that of rapidly transmitting processed data to the points of planned use and of rapidly gathering source data for processing. The available telephone and telegraph facilities are being used by employing the punched-card

transceiver. However, this is a relatively inadequate tool compared with what the data processor could effectively employ. Moreover, it requires either punched-card terminal facilities on the processor or the use of expensive conversion devices. Here again, there is development under way to provide communication facilities that are compatible with the input and output facilities available on the data processor. Soon there will be means for transmitting information from magnetic tape from one machine site directly through a communication facility to a similar tape which is generated for immediate use by the second processor located at the receiving terminal. Once this capability becomes generally available, an integrated data processing system can be fitted together that will provide prompt and effective operation even though major elements of the system are physically separated by considerable distance.

Let us turn our attention from these peripheral equipments back to the organization of the central data processor. In the main, the organization of the processor has been an extension of that used for general-purpose calculating machines. In a few instances, features have been added in recognition of the fact that logical manipulations and the flexible control over the magnetic files have comparable importance to the arithmetic operations. Thus far, there is no large-scale example of a specialized data processing facility that was planned for the massive repetitious work loads existing in some office activities. Two such examples that come to mind are those of the life insurance and annuity operations and the public utility building operations. These are the kinds of work loads to which "mass production" techniques should fit naturally. Moreover, there is reason to expect that the nature of these work loads will not undergo significant change once they have been mechanized. Where the foregoing two characteristics are present, it is natural to look to the use of specialized equipment.

Far more frequently the total office work load tends to be made of a variety of tasks. The emphasis and often the composition of these tasks show seasonal variations. For these fluid situations, the flexibility of a system patterned after a general-purpose data processor is to be preferred over the rigidity of a special-purpose processor. The degree of flexibility made possible by the use of electronic techniques and program-control magnetic tapes is quite remarkable. For example, an aircraft firm that I recently visited casually referred to the execution of several hundred routine engineering design tasks that arose during the course of one 50-hour week.

The ease and efficiency with which the data processor can be shifted from task to task permits the planning of a sizeable work load that is the combination of a number of smaller tasks. Thus, it is reasonable for a small or medium-sized organization, having a variety of office tasks, to consider using a medium-sized machine in their organization. This must be approached in the light of fact that the preparation of the programs for the machine will require just as much effort for a small work load as for a large one. One must recognize that the amount of planning and preparation for a machine application tends to be primarily dependent on the complexity of the operations rather than upon their volume. Indeed, there is a significant cost element in the planning and preparation for the use of any sized machine in which the integration of a variety of tasks is involved.

In addition to the planning and preparation effort, there is the arduously detailed task of expressing this material in a form suitable for machine use. This is normally called coding for the machine. Because this has been such a time-consuming task, particularly because of the identification and correction of coding errors, a procedure known as automatic coding has evolved. In this procedure, a great deal of the clerical effort associated with the coding can be replaced by machine operations. This has the further advantage of permitting the machine procedures to be formulated in larger aggregates than the finely detailed instructions that the machines require. Obviously, someone has to think through the exacting task of preparing the automatic coding procedures which will cause the minute machine details to be generated from statements of tasks and their interrelationships by the would-be machine user.

Up until now, automatic coding has tended to capitalize on the fact that the internal speed of the machines is greater than was needed to be in balance with the magnetic tape systems; a reduction of complexity of preparation was attained at the price of lower effective machine speed. For the more modern tape systems, this exchange may no longer be advisable except for elaborate jobs that occur only infrequently in the office activities. In scientific and technical work there is often a wide variety of small jobs, a few of which may lead to lengthy machine runs, the efficiency of the running process being not nearly so important as reduction in preparation costs. The inverse will usually be true for most office activities, the preparation costs being small compared to the integrated operating costs. In this area, operating efficiency is a most important characteristic. In the terminology of the industrial engineer: a very effective "time and motion" study must be made of this repetitious procedure which represents the source of most of the cost.

Further improvements in automatic programming techniques are in prospect. These will take into consideration the time and motion aspects in designing the translational procedures that generate the final running codes. These improved procedures should be available in the very near future and should be a significant contribution to the technology of using data processors for those routine office procedures that are in widespread use.

To supplement the help from automatic coding techniques there is further need for an adequate technique for the analysis of the problem during the planning and preparation steps. The tool that is most frequently employed is the flow diagram. These diagrams are similar to the flow process diagrams employed in a production operation, but do have a few idiosyncrasies that reflect the operation characteristics of data processors. An industrial engineer would readily adjust to this version of a familiar tool.

As we seek to cope with more intricate situations arising from the many cross-relationships in the flow of the work, there will be a trend toward some form of symbolism. It would be very helpful if there were ways to manipulate these symbols in a manner akin to those of algebraic expressions. Then it might be possible to discern the essential logical structure of a task independent of its original formulation. Out of this might come analytical procedures for relating these tasks, in whole or in part, to logically equivalent tasks that have already been formulated. If feasible, this would open the way to borrowing from previous work and that of contemporaries, and thereby avoid the expensive and time-consuming effort of reprogramming jobs. At this time, I can only point to the need; I know of no successful research activity of this sort that has been reported. I am confident that this aspect will demand more and more attention as automatic data processing is applied to more sophisticated clerical tasks of the office.

You may wonder about the implied complexity that is not evident in office work when compared to such imposing tasks as solving complicated mathematical equations. If the machine can solve equations, why isn't it more than adequate for the simple humdrum tasks of the office? The answer is the fact that when a situation can be naturally formulated in a set of mathematical equations, a beautiful regularity has been observed in or imposed upon the situation. Such regularity almost never appears in office procedures. We can look forward to the time when we will have a symbolic notation that will be suited to the represenation of our office procedures in a form that is comparable to those

of mathematics. In the meanwhile, we will have to continue to work with the relatively crude flow diagrams which, together with appended text, contain the logical structure of the processes.

Whenever one has carefully worked out his office routines for manual or even punched card procedures, there is a strong tendency to assume that the same work pattern can be transferred to the automatic data processing facility with only minor adjustments. Unfortunately, this is usually far from true. While as a transition procedure this may be helpful in training the staff associated with the new equipment, it will almost invariably lead to redoing the work once sufficient experience has been gained with the new facility. Occasionally a small voice is raised for a careful rethinking of the job patterns and the flow of work before electronic processing is attempted. This voice is usually disregarded. Indeed, even when the voice is heeded, the importance and the magnitude of the rethinking effort are seldom appreciated at the outset. More often than not it is interpreted as a fix-up operation that make the procedures a little neater and a bit more comprehensive.

To emphasize the extent to which rethinking may have to be carried, consider the following analogy: An emergency has been declared and all essential activities are being assigned priorities for manpower utilization. Your office activities are to be continued, but obviously at a low priority. However, you are surprised at the painfully low priority that the survey team assigns: You may retain only those of your staff who have had five or more years of supervisory experience; all others are assigned to more urgent activities. The senior staff remaining must help you build anew with ample replacement personnel that are to be brought in from Lower Slobovia. This new staff will have visas that are valid only for the duration of the emergency, after which they are to be sent back. Thus, these people will have no future to look to and will not be motivated to improvement and growth through identification with your organization.

Moreover, you learn that public schooling ends in Lower Slobovia with the fifth grade. You can only depend upon these people to add, subtract, multiply, and divide; write legibly and read what they have written; and respond to simple instructions! Since they were raised in an environment that has given them an unusual respect for authority, you can also depend on them to carry out instructions as they are given.

While conscientious and reliable, they tend to be completely literal-minded and will do nothing other than what has been explicitly assigned for them to do.

To add to your burden, very limited language skills are imparted to them in their school system. To offset this, the new staff is to be taught to respond to, but not understand, about 50 simple statements during the time that they are in passage. All of your office procedures must be expressed by means of a selected sequence of these 50 statements, which are known to be logically sufficient for the purpose. While it is possible to add a limited number of new statements or redefine the desired response after they have reported for duty, this is not advisable because such adjustments come slowly to this staff and lead to a period of confusion betwen them and the supervisors. However, there is one statement that cannot be included: "You see what I mean, don't you? O.K., now you take it from here."

Now for the crowning restriction! Upon their arrival, the Public Health officials notify you that all of the new staff have been found to be carriers of a dangerous contagious disease to which they have become immune. It will be necessary always to keep them in an isolated location so that no Americans can come in direct contact with them. This means that all of your procedures must be carefully adjusted to function effectively even though all communications and work assignments between your supervisors and this new staff must be conducted through telegraph messages.

This then is the specialized character of the new staff with which you must now operate your activity. You must rethink all of your procedures so that your routine clerical activities can effectively make use of this staff. Obviously, few of us have had occasion to organize our work to cope with such conditions. While it is not a task beyond the doing, it is a task for which there is almost no body of previous experience. In the light of this analogy, it is both reasonable and prudent to examine thoughtfully whether an existing efficient manual system can profitably be transferred to this kind of automatic processor. Indeed, if one follows the above analogy through in relation to the optimistic prognosis for the impending impact of computer techniques in the office, it follows that this "new staff" can be organized to do the job both better and at a lower cost. Certainly, one must be aware that this prognosis may prove to be an overly simplified estimate of the situation.

In my remaining time I will discuss briefly the newer technology and some of its implications. Without doubt, in the next three to five years there will be a considerable increase in operating speeds of the arithmetic and logic units. Perhaps you have already heard some of these claims: speed increases that range between 5 and 20 times those now available. This increase will have considerable significance to applications in the physical sciences and engineering design. Indeed, their special requirements have triggered this new round of effort. For the areas of application that are of interest to our discussion here, these increases in speed are probably going to be of limited significance. At the moment, the existing technology gives far more speed than we have learned to employ effectively. However, some of the new technology also makes it possible to reduce significantly the heat generated and the size associated with present equipment. This will tend to reduce present troublesome installation considerations.

One technical improvement that is of immediate interest is the coming availability of large amounts of high-speed storage. This should make it far easier to plan for and use the processors. Furthermore, this large internal storage will open up a wider range of practical applications wherein sorting and search are dominant operations. Moreover, procedures that are characterized by combinatorial aspects will also be more amenable to machine processing. An example of this sort arises in connection with the evaluation of all meaningful configurations of a production schedule. Even though there is presently lacking an analytical means for selecting among these configurations by some quasi-mathematical technique, it may be adequate for the moment to generate all meaningful situations and then rapidly scan them for the ones that have acceptable characteristics.

In addition to large amounts of high-speed memory, there are situations that call for large amounts of lower-speed direct-access storage. At present the approach being taken is through the development of magnetic "files" and various forms of magnetic "books". The most important examples are in the fields of record-keeping and file references. Here the daily incidence of search requests are a small fraction of the total volume being held. Furthermore, these searches tend to be randomly distributed throughout the holdings. This is in contrast to the situation for ordinary accounting work where the activity for the period has been batched by using cyclic billing procedures and each batch is related to a specific range of the total file. Problems to which such techniques

would be particularly applicable are represented by requests into a personnel file in which the identifying characteristics are not the ordinary ones by which the file has been arranged for its routine maintenance.

Along with improved technology, there will need to be considerable improvement in the methods that will be used for updating and interrogating large-volume files. An extreme example of this class of work arises in connection with the selective searching of the Patent Office holdings and the abstracts of the physical and the biological sciences. These interests are supplying incentives for the technical developments needed to expedite this application for automatic techniques. Even the preliminary explorations into these areas have raised intricate intellectual concepts as well as challenging technical problems.

I am pleased to have had this opportunity to address you and tell you about subjects which I considered to be of mutual interest. If I have neglected any specific area of your interest, I will be happy to try to cover these during the Question Period.

Thank you very much for your interest and attention.

"OBJECTIVE TIME STUDY WITH STATISTICAL CONTROLS"

C. J. Allen, Chief Industrial Engineer,
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Meat packing is an industry who jobs are characterized by a great deal of skilled manual activity with numerous motions and complex patterns. They are also of long duration in that the specifications of the raw material and the finished product do not have annual model changes and standards set on jobs must be suitable for a long time application. Further, as it is natural, the time study group is used as a recruiting ground for other managerial positions. In order to obtain a long standing concept of "normal" performance, in order to produce engineered standards, representing measurement rather than value judgements; standards that are consistent and accurate, recourse was made to a modified time study technique known as "Objective Rating". In order to maintain controls the source of standards, the concept of "normal" present in the minds of time study group was documented in a benchmark film loop. Statistical procedures were introduced to control (in the statistical sense) the application of the concept of standard from period to period.

Before I get into the detail of the application of the modified time study technique and our statistical control I would like to give you an insight on the operations performed at Cudahy Brothers Company. The plant is located in Cudahy, Wisconsin, a suburb of Milwaukee. It is a complete packing operation from the slaughtering of hogs, calves, lambs and cattle to the final processing and packaging of products. We have approximately 1400 production employees, of which about 85% are on an incentive pay plan. The incentive plan is a standard hour system. These standards are applied in several different ways, individual standars, small group standards, large group standards and standards applied on departmental basis going as high as 80 employees operating on one standard.

SLIDES 1 - 2 - 3 - 4 - 5 (TYPICAL PLANT OPERATIONS)

As you can see on the slides just shown, some of our operations such as boning and other knife work, have complex motion patterns which are very hard to follow and analyze by observation. As might be visualized it is very difficult to correctly describe in detail the motion patterns followed, therefore we have turned to motion picture films for permanent records of the methods used when the standard is established or in many cases for actually analyzing the operation and setting the standard. "Memo-motion" filming techniques (100 frames per minute or 60 frames per minute) have also proved very useful, particularly on long cycle operations for group analysis.

The standards were established in 1945, about the same time as the Union, The United Packinghouse Workers, - CIO, was recognized at the Cudahy Plant. As a consequence the present labor contract quite completely covers the operation of the incentive system. There are only a few departments in which the company has not established production standards.

We do not feel that we have found a perfect answer, to the problem of controlling standards. However, I do feel that we have gone a long way in improving our rating techniques, and therefore controlling our standards. I don't believe that any perfect answer to the rating problem will be found, until someone invents a machine, meter, or gadget that can be hooked onto the worker being observed which will record his pace, effort, and efficiency. I will show to you a technique for improving time study rating practices. This technique is a big improvement on common practice. It is merely a theory but has been working in our plant for over three years. I will show you what it is, how Cudahy Brothers Company went about installing it, and what we have achieved by using this objective rating procedure.

We have been troubled in the past with inconsistent standards (from inconsistent ratings in addition to other problems), despite considerable practice by our time study men with S.A.M. film and other available rating training aids, such as dealing cards, walking and such. In hopes of improving the consistency and accuracy of our standards (in order to achieve better schedules, a better pricing structure, or a more equitable wage structure, and all the other advantages of accurate standards) we decided to try this new technique.

In many ways perhaps, this new technique is not as new as I may make it sound. It is merely a reversal of the steps employed in time study rating, but this reversal produces radical differences.

The common practice for rating performance, in order to level time study, requires that the time study man perform the necessary (essentially two) steps.

1. He must judge the difficulty of the job being observed and form a mental concept of what normal or standard performance would look like on the specific job.

2. He compares the performance he observes to this mental concept of standard performance and places a numerical value on this appraisal.

Objective time study requires similar steps but in reverse order:

1. The time study man using objective rating first rates the speed of performance in comparison to a standard speed which is the same for all jobs regardless of the difficulty. Consequently, this standard of speed may be embodied in a single concrete form.

2. The time study man then adjusts this rated time for the difficulty of the job by the application of a table expressing the effect of various difficulty in a percentage fashion.

This reversal of the common procedure gives us two unique advantages. First, inasmuch as the standard speed against which judgement is made is the same for all jobs, this may be embodied in a single simple film and any judgement for rating is made between the performance observed and this film or a recollection of it. In other words, any two people rating are judging between the same two things, rather than between the performance and an unreliable mental image. The second advantage is that the judgement for difficulty is made from a table developed in respect to objective factors, producing a much more consistant adjustment for difficulty than is obtained when the entire judgement for difficulty is performed mentally than by the time study men.

These are not idle theoretical claims. I will show you the performance of the time study men in our plant, over a 18 months period indicating the changes brought about in the accuracy and reliability of the rating by the introduction of this altered rating procedure.

To get back on the track, and in order to keep things in their proper chronological order, let me go through, step by step, the six steps used by Cudahy Brothers to convert our time study department to this new method of rating. First course, was the decision by top management to alter the method of rating in order to achieve better results. This decision was made high enough in the organization to encourage the time study men to do their best to comply. Doctor M. E. Mundel, was hired on a consulting basis to help install the "Objective Rating" technique outlined in his textbook "Motion and Time Study". The able assistance of Dr. Mundel, throughout the installation, and the subsequent follow-up, without a doubt contributed immeasurably to its success.

Second, a very simple job was selected in the plant and a large amount of motion film was taken of several operators performing the simple task at many different speeds. From the film that was taken 20 film loops (endless pieces of film) were made, each showing a different speed of performing the same task, using an identical work method. These 20 films were selected to display as wide a range of performance on this job as possible. Let me show you one of these loops.

(MOTION PICTURE SHOWN)

Third, a rating session was held with key members of top management and all of the time study men. These 20 films were presented to this group in random order of pace. The group was requested to consider each performance and to answer these questions: Is this operator working at a pace sufficient to earn daywork? Is the operator working at a pace greater or less than required to earn daywork? Is the worker working at a pace such as to merit the typical incentive increment the incentive workers are expected to earn? The group was further requested to assign a numerical value to each film with a typical incentive worker working at a typical incentive pace noted by a 125% rating, this being the figure established by the Labor Contract.

It has been said many times before that the entire time study procedure is a value judgement process.

This particular rating session to which I am referring certainly could be characterized by this term. Management was making a value - judgement concerning the pace of work they expected in order to earn typical incentive wages.

However, as I will show you, this one valued judgement is then used subsequently as a basis for true measurement of other jobs. Value judgement is, of course, necessary in making the initial basic conversion between money and performance. However, if we can reduce value judgement to the single occasion when the initial decision is made and subsequently perform true measurement, I believe we have made a considerable advance in our time study procedure.

To continue with my description of the rating session, as you might have expected, the men were not consistent either with themselves or with each other. That is, the different ratings assigned with the different films did not accurately reflect the differences in time, nor did the men tend to make the same error each time, either in direction or amount. Consequently we attempted to mathematically sort out all the ratings given us in order to determine what the man was really saying. A simple but extremely helpful mathematical technique was employed.

As a preliminary step, we assigned a rating arbitrarily to one of the films. We then calculated what ratings would have to be assigned to the other 19 of the 20 films in order to be consistent with this first rating, such that when each film's cycle time was multiplied by its rating we would get a constant value, this being the essence of consistent rating. Thus, we had for each film, an "arbitrary" rating. For each film we also obtained an average rating as assigned by the group. In order to get a consistent series of ratings best reflecting the total opinion of the group and yet in the correct proportion for each film, we said "let us multiply the arbitrary ratings by a value K, such that when the group's average ratings are plotted against the corrected arbitrary ratings, the sum of the squares of the deviation about a 45 degree line (the line of absolute consistent rating) will be at a minimum". The calculations are relatively simple and are shown on the next slide.

(SLIDE)

Fourth, in our procedure, we return to management at a later session with the film, presenting both the films and the rating value which best reflected their total concept of normal and were, for the 20 films, in the correct relationship to each other. The group finally agreed on one of the films as representing 100% performance. Consequently, each of the other films could be assigned a value representing the performance displayed.

Fifth, in our procedure, 12 of these films were selected to provide a rating scale for the time study department.

Let me show you how the average ratings from a group compared with the best estimate of what they should have assigned. This was in December of 1953.

(SLIDE)

Notice that the entire group tended to rate the low performances too high, the high performances too low. Notice also, the error was considerable. This is not a unique phenomenon. It must also be borne in mind that this group represents a highly trained time study department.

In order to present the scale of speed in a convenient form, to instruct the time study men as to what standard speed looked like 12 of these film loops were combined into a single film which we call our "Multi-Image Film" or "Benchmark Film". This film represents not only a standard speed but known variations thereof in order to give a man the scale of speed to measure with. (SLIDE SCALE OF SPEEDS) (FILM OF 12 SPEEDS)

At Cudahy Brothers Company a loop of this benchmark film was set up in the projector in the time study department. The men were given opportunity half an hour exposure to it daily until they became thoroughly familiar with all these variations of standards speed. It was also made a standard practice for each time study man prior to going into the shop to set a standard, to refresh his memory of this scale of speed by a quick view of the loop. As we advanced further into the procedure this multi-image benchmark became firmly planted in minds of the time study men and it was not necessary for them to view this multi-image loop quite as often, however, they still view this loop at least once a week and quite frequently more often.

As a sixth main step installing this new rating procedure, from research data available, we presented to the time study group a standard scale of adjustments (3) for difficulty as shown in the next slide.
(SLIDE)
This data has since been authenticated by actual application in the plant and in some cases it was found necessary to extend the difficulty corrections beyond those originally outlined in the table.

Let me review for you the steps in time study procedure which this group is now using: They record the method and observe an operator and record time values on the job in the usual manner. However, when it comes to the job of rating, they will evaluate the operator's rate of activity (the rate of acceleration and de-acceleration of his movements) not against what they think could be maintained on this job, but merely a comparison of the speeds of performance exhibited on the benchmark film loop. They record the relative value as a rating. Whether the job is light or heavy the same scale is used. The judgement is between the recollection of one single normal speed and the variations thereof, as demonstrated on the loop film, rather against what the time study men thinks possible on the job.

Next, to each element, the time study man adds a percentage taken from the table of adjustment, shown previously, adding to each element a percentage equal to the sum of the highest applicable percentage of each of the categories given on the table.

Let us examine the results obtained to this new rating procedure. First, I would like to show you again the rating chart of the group the first time.

(SLIDE)

Notice the trend. The men are not capable, even as a group, of accurately rating even moderate departures from normal speed. We could even seriously question the stability of the concept of normal. The next slide shows a group plot for April 1955. It should be mentioned that this April plot is with 10 new films of another operation not seen before by the group, hence it is not the case of memorizing films.

(SLIDE)

Of greater interest though, than this overall rough analysis, is a thorough statistical analysis of what happened during these 17 months.

Each month we test our time study group by asking them to rate a set of 10 new films of an operation not previously rated by them. We assign correct values to these 10 new films by a procedure similar to that used on the first set. In order to get a meaningful statistic, which would permit real analysis, we took the rating made by each time study man on each film and divided it by the rating we should have assigned. This gave a percentage of correct rating assigned. This also gave us a statistic which was not a function numerically of the particular speed presented. Also, inasmuch as each time study man rated 10 films, this permitted us to also compute the range of error by men for the group, standard deviations, etc. For instance, let us say on one job he only assigned to one film 76% of the rating which he should have assigned, on another film he assigned 126% of the correct rating. This gave him a range of error of 50%. For the group of 8 men we computed the average percent of correct rating of each film and the range of % of correct ratings assigned by the 8 men for each film. We plotted these on a typical Quality Control Chart in order to examine the degree of control (if any) we had and to help us determine which particular films apparently had assignable causes of variation (out of control.)

(SLIDES)

Note that the out of control conditions displayed on high and low ratings and also note the ranges are so large that it is impossible to even chart them on this particular form. Let us show you, month by month the changes in ratings by our time study group.

Note in March 1954 the control pattern radically changed. In April 1954 we obtained statistical control. By June 1954 we not only had control but a reduction of control limits. By September 1954 the group displayed almost a mechanical control pattern. This condition has been maintained ever since. In fact, group out of control points when they do occur usually indicate a poorly made film.

Let us look at the controls chart from April 1955.

(SLIDE)

The group is out of control on one film. Further examination of this film indicated that there was a method variation, and that the rating was not comparable. In short, the ratings had become more accurate than the films which we were producing.

Let us also examine the effect of this rating procedure in respect to individual time study men. The next slide I have plotted a control chart by men.

(SLIDE)

Note, that when we began in December 1953, certain of the time study men were out of control, that is, the ratings tended to be different by more than just chance error would cause, from the group's average values. Note, as we proceed, control is finally obtained and in April 1955 we can say that other than for chance cause differences, the standards set any man would be essentially the same. Let us connect this with our other control charts. "We may say the standards set in our plant are essentially the same regardless of the pace of the operator for the time study man doing the rating except for chance differences accompanying each such situation". This is now measurement rather than "value judgment".

Please note also, that each month, our group was tested with new films to prevent the phenomenon which has fooled so many people in the field. If time study men are tested by the same films periodically, they become so accustomed to the particular values employed that they learn to identify them within 1% not by improving their ability to rate, but by exercising their memory as to what should be assigned to the particular films.

I should like to indicate several by-products of this procedure and the control sessions. The next control chart is for our time study man "B".

(SLIDE)

Time study man "B" early in the program is erratic. First he was too loose, then he was too tight, later he was brought under control (rating like the rest of the group), but in the process of doing so, his range went up again, although it is by no means as high as it was originally. (In the early days of program we could not even get him on the chart). By having this information at my disposal, I very carefully watched the progress of this time study man, and gave him a lot of extra training. This man has now found himself and has remained under control.

The next slide indicates another interesting phenomenon that we have observed several times.

(SLIDE)

Time study man "F" as you will note, from early in the program exhibited a good degree of control. He was essentially like the group but with only chance variation. His range tended to be considerably lower than the group, but in April 1955, we suddenly find him out of control on the tight side. Further investigation of this result which statistical analysis tells us, probably has an assignable cause, indicated this man had (due to certain internal procedures in the plant) been passed over for a raise and seeking other employment. He was somewhat bitter about the plant and in a generally pessimistic mood. This was reflected in his ratings. I might add that we have observed this phenomenon several times, to the point that we can predict when a time study is going to go out of control. We have found that when a time study man is emotionally disturbed his ratings go out of control. This has been very worthwhile for us. Not that we have used it to say "stop annoying the time study men" but we have certainly avoided putting them into critical situations when we know something is disturbing them emotionally. This also has, we believe, improved the quality of our standards.

Now as to the overall effect on the plant. Because of the pressure of business and the Unions statesmanship-like appreciation of the need to remain competitive, we have been able to negotiate a contract with our Union giving the management the privilege for the period of one year, to modify any or all incentive rates in the plant as necessary in order to make them equitable, and in line with the basic concept of work pace. Remember, our design objective was to set the standards that would produce a 25% incentive earnings when worked at by a skilled group diligently exercising itself. The plant is averaging 125%. This appears to represent a free working situation, rather than one of enforced restriction of output, because of the distribution of hours earned. We have been having the plant computing or tabulating equipment while it runs the payroll, pick up the number of hours earned at each percent incentive increment, and I would like to show you on the next slide, the typical normal distribution attained.

(SLIDE)

Note, 125% is the approximate midpoint but the range extends all the way below 100 to over 150%. This condition is usually obtainable when the situation is primarily reflecting normal distribution of individual rather than a hetrogenious application of poorly set rates.

Some additional remarks are in order. We have brought the rating process under statistical "control". This is important. A very high order of accuracy is possible in those cases where it is economically feasible. Since only a chance variation exists between different ratings for the same performance, having more than one man rate a performance permits us to average the value, increasing the reliability of the average. Remember that our rating process is under statistical control, and a large percentage of values will be of acceptable accuracy, but the "natural tolerance of the process" still permit a chance production of values varying from the true value by more than we would desire. Again the statistical control gained is a great help. Since only chance differences exist, an average of several values is better than a single rating and in dubious cases we can have several studies made. In fact, in April 1955, all our ratings of our test films when combined, gave us a figure probably accurate to within a few percent.

In Summary: The objective time study procedure I have been attempting to show you, employs more or less the same steps as in the normal procedure except in reverse order.

The time study man rates the speed of performance against the standards speed without paying attention to the difficulty of the particular job being observed and afterwards allows for the difficulty of the job from a table. This permits all time study men to judge between the same two things and to adjust for difficulty by means of a systematic, observable, correctable, comparable method.

We have brought our time study men into statistical control in that chance differences exist between rates set on a job, by any two time study men and only chance differences exist between the standards set regardless of the speed of performance observed the time the study was made.

It is my belief that we are approaching a true measurement rather than a series of valued judgements. The single initial valued judgment, the conversion of performance into money has been performed by top management, once it should be performed.

By means of objective rating techniques, statistical control was established and has been maintained. Further, the plant incentive earnings presently reflect a chance distribution of employees capacities rather than a skewing or bias or restriction of output and the mean of this

distribution very closely approximates the design point or contract concept expectable incentive. The distribution of earnings is in statistical control to the extent where changes in the shape of the earning distribution curve usually reflect assignable causes within the administration of the plant.

The existence of statistical control on time study men and on plant earnings continually monitor the situation so as to indicate occasions when an assignable cause should be sought and remedial action taken.

MEASURING WORK BY SAMPLING METHODS

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Random sampling for measuring delays and idle time of men and machines has been used in industry for over twenty years[42] while work sampling for establishing time standards for manual tasks is a more recent development.

L. H. C. Tippett laid the groundwork for the ratio-delay method of measuring idle time and our studies as well as those of others seem to indicate that random sampling also can be used to measure work.

Work sampling employs the random sampling theory similar to that used in quality control. The method consists of selecting samples at random from a large group and when a sufficient number of samples has been selected, a prediction is made for the whole group.

The determination of the percentage of the working day that the operator or machine is working or idle is based upon the theory that the percentage number of observations recording the man or machine as idle is a reliable measure of the percentage time that the operation is in the delay state, if sufficient observations are taken.

What Work Sampling Can Do

1. Where there is a clear distinction between working time and idle time, work sampling will give time standards for repetitive manual tasks which are substantially the same as standards obtained by time study.

2. For an activity where a production count is not easy to obtain, such as indirect labor operations, it is possible to obtain a performance index of the operator studied during the period studied using performance sampling

3. The measurements mentioned above can be made with a pre-assigned degree of reliability.

4. Work can be measured by sampling in many instances in less time and at less cost than is required by time study.

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[42] See Bibliography at end of paper.

5. With work sampling the analyst makes an instantaneous observation of the operator at random intervals during the working day, thus making prolonged time studies unnecessary.

6. No stop watch or other timing device is needed for work sampling.

7. Work sampling studies may be made over a period of days or weeks, thus decreasing the chance of day-to-day or week-to-week variations affecting the results.

8. This type of study may be interrupted at any time without affecting the results.

9. Even in a plant where methods are not standardized and job descriptions are nonexistent, a performance index by operator or by department can be obtained. Also, the work sampling data could show the percentage of idle time and delays, and a breakdown of the various reasons for the non-productive time.

Although sampling can be used for measuring work it should be pointed out that time study, elemental data, or motion-time data in most instances would be preferred for establishing time standards on short cycle repetitive operations. Work sampling often can be used profitably for measuring non-repetitive operations, activities where people work in groups, and activities which do not lend themselves to measurement by time study.

It is possible by work sampling to determine the percent of the day that a person is idle and the percent of the day that he is working, as well as the average performance index or speed at which he worked during the "working" portion of the day. For example, assume that John Smith works an eight-hour day as a drill press operator. A work sampling study might show that he was idle 15% of the day or 72 minutes (480 x .15 = 72) and that he worked the remainder of the day, or 408 minutes at an average performance index of 110%. If the record shows that he turned out 420 pieces of acceptable quality during the day then the standard time for the operation he performed could be computed as shown in Fig. 1.

The assumption is made that the allowances for this drill press operation would be taken from the Company Time Study Manual. Seldom would the allowances be the same as the "idle time" of the operator during the period the work sampling study was made.

The same rigorous analyses would be required of work sampling as of time study in establishing a time standard. The method of performing the operation would have to be standardized and a detailed written description prepared. Quality standards would be required, as well as assurance from the foreman that the job was running the way it should. During the study the analyst would not only make an instantaneous observation as to whether the operator was working or idle but if working, the analyst would rate the operator's speed and note whether he was performing a regular part of the cycle of work. Information would be obtained as to the starting time and quitting time as well as the total number of parts of acceptable quality finished during the day. The sampling study could be counted upon to measure with a pre-assigned degree of accuracy the percentage of the eight-hour day that the operator was working on the regular drill press operation, and his average performance index or speed for the working portion of the day.

Establishing Time Standard for an Assembly Operation

The following case[7] illustrates how a time standard was established on a mechanical sub-assembly operation by work sampling.

Ten operators regularly performed this job and all ten were studied during a three-day period. Two hundred-forty observations were made each day making a total of 720 observations. Of this number the analyst found the ten operators working 711 times and the performance index was noted and recorded for each of the 711 observations. Nine times during the three-day period the analyst observed the operators idle. (See Fig. 2).

As the summary of the results of the study shows (see Fig. 3) the "Total time expended by the operators", including working time and idle time, was 13,650 minutes. The working time in percent was 98.7% (711/720 x 100 = 98.7%). The remainder or 1.3% was idle time. The number of minutes of working time was 13,473 (13,650 x 98.7 = 13,473). During this time the ten operators turned out 16,314 sub-assemblies of acceptable quality. The average performance index of this group was 123.6%. Figure 2 shows a summary of the performance index for the 711 observations and shows how the average performance index was determined. The computations showing how the standard time was determined for this operation are given at the bottom of Fig. 3.

Some Examples of Work Sampling Applications

You may be interested in some examples of actual applications of work sampling together with the results of each.

Work Measurement of a Warehouse Handling Group

The object of this study was to measure the work and install a wage incentive plan for thirty people employed in a film warehouse. The time standards were established by work sampling. The men were engaged in receiving materials, storing and stacking, filling orders, packing, shipping, reoperating (opening and repacking for tests, etc.), and record keeping. Mark-sensing IBM cards were used to aid in collecting and analyzing the data. The work measurement and wage incentive installation resulted in an annual saving to the company of $45,000.00 per year. Considerably less time was required in making this installation through the use of work sampling than would have been the case had a continuous time study been used.[22]

Operations in Fruit Packing Houses

The work sampling method was used in studies of work in deciduous fruit packing houses in California. These studies included operations in 22 plants in which the number of job classifications varied from 12 to 45 and the total number of workers per plant ranged from 25 to 180. The studies were made to obtain three types of data: (1) The proportion of the nonproductive time to the total working time, (2) Time requirements per work unit for specific jobs, (3) The flow pattern in materials handling. It is estimated that the field time required 80 percent less time than would have been necessary to obtain a one-day production study of each job.[37]

Measurement of Office Work

The initial study using work sampling was made of four girls typing customer invoices in the Central Typing Section of an oil refinery. The results of this study were so promising that this company has used the work sampling technique for establishing performance standards for planning and scheduling purposes, for non-financial measurement purposes, and for individual wage incentive applications.[3]

Methods Study of Polishing Chromium Chair Parts

This operation consisted of polishing steel tubing parts for chromium kitchen chairs using a sisal buffer. Operators worked on this job during the three shifts of the twenty-four hour day. As a result of a careful study the very best method of polishing each of the parts of the chair was developed and the operators were taught to use this method. Even though the operators were experienced on this work, it was apparent that there was variation in the method. The main difference in the method was a difference in the number of strokes or passes against the polishing wheel per piece. Random sampling was used to measure the variation from the standard method which had been developed for the job. This enabled the industrial engineer to arrive at a new "standard method" for performing the polishing operation and this was used as a basis for establishing time standards on this operation.[7]

Comparison of Working Time Obtained from Time Study and from Work Sampling

This company made an investigation to determine the accuracy and the cost of measuring work by time study and by work sampling. This organization uses time standards for planning and control purposes. The results of two of their studies are shown in Fig. 4. Due to the nature of the activity the percentage of the day that the operators worked was low -- 46.6% as determined by time study and 44.8% by work sampling in Study No. 1. In Study No. 2 the percentage was 54.5% and 51.0% respectively. As the data in Fig. 4 show, the cost of making work sampling studies was much lower than the cost of making time studies. The general conclusion resulting from the study was that in the future, work sampling should be used instead of time study for measuring work -- that work sampling would cost only 2.6% as much as time study.

PERFORMANCE SAMPLING

The following is for the most part an abstract of a paper published in the November-December 1955 issue of The Journal of Industrial Engineering.[1]

Introduction

In 1934 L. H. C. Tippett described a statistical method which he had developed in the English textile industry to measure operator and machine delays.[42] R. L. Morrow was one of the first people in this country to use Tippett's methods and this technique has come to be known as the Ratio-Delay method.

In 1940 we started our statistical studies of work measurement, and a summary of some of our findings was published in 1950. That report[18] presented evidence as to the reliability, validity, and practicability of the ratio-delay method as applied to manufacturing operations in this country. Over the years the ratio-delay method has found increasing use, and numerous articles have been published describing applications of this technique.

From the outset we believed that sampling could be used to measure work and a few people have used sampling for this purpose. However, no one has studied the type of statistical distribution which is representative of performance levels of manually paced operations, nor has a specific statistical technique been developed based upon the appropriate distribution and which is applicable to work measurement. This report contains the results of several studies of ours pertaining to performance sampling in work measurement, including a comparison of performance sampling and time study as means of measuring industrial operations.

General Conclusions

Our main conclusion is that where there is a clear distinction between working time and idle time, work sampling will give time standards for repetitive manual

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1. "Performance Sampling in Work Measurement," by Ralph M. Barnes and Robert B. Andrews, The Journal of Industrial Engineering, Vol. VI, no. 6, pp. 8 - 18, November-December, 1955.

tasks which are substantially the same as standards obtained by time study. Moreover, sampling measurements can be made with a pre-assigned reliability. Even in a plant where methods are not standardized and where job descriptions are nonexistent a performance index by operator or by department can be obtained by work sampling. Also, the work sampling data could show the percentage of idle time and delays, and a breakdown of the various reasons for the nonproductive time.

We believe that work sampling provides a valuable tool for measuring work, and that this simple inexpensive method will find wide use in many areas where manual work is performed.

Acknowledgements

The authors want to express their sincere appreciation to all those who participated in this study. Special thanks are due E. S. Buffa, Donald C. Demangate, J. A. Gary, Professor E. P. Coleman and Professor Paul G. Hoel who assisted with various phases of this investigation. We are also greatly indebted to the organizations that so generously participated in the validation study and whose identity we agreed not to reveal.

Objective:

This project was undertaken to develop a sampling technique which would provide an accurate and economical method of determining, with a pre-assigned reliability, the performance level of labor activities. The technique was to be applicable to any well defined physical activity which could be affected by the worker's skill and effort.

Scope of the Investigation:

The study of the applicability of statistical sampling methods to work measurement was divided into three main phases:

I. The investigation of the type of statistical distribution which is representative of performance levels of manually paced operations.

II. The development of a specific statistical technique based upon the appropriate distribution and applicable to work measurement.

III. The testing of the validity of the proposed statistical method by studies actually carried on in industrial organizations.

Phases I and II:

Detailed descriptions and the results of Phases I and II have been published.[8] The investigation of the nature of the distribution which is representative of performance indices resulted in a strong rejection of the hypothesis that such indices are normally distributed.[11] Because of this result, non-parametric methods were used to derive the relationships applicable to performance sampling. The basic equation governing performance sampling of work was determined to be $n_m = \frac{\sigma^2}{d^2 a}$, where the quantities are as defined in Appendix I.[10]

Phase III - Test of the Validity of Work Measurement by Performance Sampling.

Procedure

To validate performance sampling as a method of measuring work, it would be desirable to compare its results with other accepted methods of measuring work. Since time study is the most widely used method, performance sampling was tested against time study. The procedure for evaluating the proposed technique was a comparison of the normal time established by performance sampling, for each selected operation studied, with its corresponding normal time obtained by time study.

The necessary data were obtained under actual factory conditions through the cooperation of several industrial organizations. The actual studies were made by experienced industrial engineers of the cooperating firms. The studies which the participating companies were asked to make consisted of four main parts:

1. The selection of the operation to be studied.

2. The definition of the elements of the selected operation which were to be measured and the establishment of a normal time for the defined operation.

3. The taking of a random sample of:

a. The productive effort applied to the measured work elements.

b. The machine-controlled portion of the operation.

c. The unmeasured work.

d. The delays, personal, avoidable, and unavoidable.

4. The compilation of additional necessary information, including:

a. The actual total time spent by each operator in the experimental group during the period of the study.

b. The total number of units of work produced by each operator in the experimental group during the period of the study.

The selection of the operation to be studied was based upon certain definite requirements:

1. It must have had a standarized method.

2. The operators must have been experienced in the particular operation and have been following the prescribed method.

3. An additional restriction was placed upon operations which were partially machine controlled. The machine-controlled portion must have constituted from 15 to 85% of the total normal cycle time. To attain the desired accuracy with the desired statistical confidence, machine-controlled portions outside these limits would have required a prohibitively large sample size.

Once the operation to be studied had been selected, it was necessary to clearly define the elements to be included in the measured work category. In general, the criterion used for making this decision was the frequency of occurrence of each element. Those elements which occurred at least once each cycle were measured. Less frequent elements such as inspection, recording production counts, lining trays, etc., were classified as unmeasured work. The elimination of these infrequent elements tended to increase the reliability of time study. The variation in the time duration of such elements is usually greater than in cyclical elements. This is particularly significant because the number of occurrences of such elements which are timed during a time study is typically small.

Since only experienced industrial engineers were utilized, the exact method of conducting the time study was left to

the individual preference of the engineer. It was suggested that it be conducted according to the procedure regularly employed in the particular plant. It was considered essential that the same engineer make both the time study and the performance sampling study. This precaution eliminated one source of possible error -- differences between raters in their concept of normal performance.

Another possible source of error was eliminated by restricting the validation procedure to only the measured portion of the total actual working time. Thus, the comparison was made between the normal times established by performance sampling and by time study. Allowances were not included in the time study and, except for their use in ratio-delay analysis, personal, unavoidable and avoidable delays were excluded from performance sampling. This made it necessary to insure that a sufficient number of observations were taken to permit ratio-delay analyses to be made with the desired confidence. The number of observations necessary to determine the percent of the total actual time spent on measured work, within the desired accuracy, exceeded that required for performance sampling. Hence, the ratio-delay requirement was the determining factor in choosing the required sample size. A sample size of 600 observations was decided upon as a compromise between sample reliability and minimizing the demands upon the company. This sample size, with 95% confidence, resulted in absolute errors of $\pm$2.4% and $\pm$3.2% in the percent of actual time spent on measured work when the delays and unmeasured work totalled 10% and 20% respectively of the actual time.

The number of operators, individually measured and simultaneously performing the selected operation, determined the number of sampling trips required to give a total of 600 observations. For example, if there were five operators, 120 (5 x 120 = 600) sampling trips would be required. Once the number of trips had been established, the trip times themselves could be determined. The method used to select the sampling times was exceedingly important. Estimations of sampling errors are dependent upon a knowledge of the probability with which individual observations would be included in a sample. By simple random sampling, all possible combinations of observations, comprising a sample of a given size, will have equal probabilities of being selected. Trip times were randomized to maintain statistical validity.

The procedure used in making the actual performance sampling was as follows:

1. Observations were made of each operator in the experimental group at the selected times.

2. At the instance that the observer viewed each operator, the state of the operation was noted.

a. If the element observed was classified as measured work, the operator was rated and his performance level was recorded. Appendix III contains a brief description of an exploratory study into the effect of the length of observation time on performance ratings.

b. If the operation was in a delay or unmeasured work state it so was recorded.

The engineer making the study was supplied with written procedural instructions which included a table of random sampling times. Performance sampling data sheets were also provided.

Results

The results of the studies made are summarized in Table I. The following guide to the chart explains each column. The illustrative figures are those actually used in computing the various quantities for the Company A study, line 1 of the Table.

As an illustration of the results which would have been obtained if smaller size samples had been taken, Table I includes the results of 50% and 25% sub-samples of each full study. These sub-samples were obtained by systematic sampling of the original observations of each study. The systematic sampling plan for taking the 50% sub-sample consisted of selecting at random either 1 or 2 as the starting point and taking every second observation thereafter in the chronological order in which observations were originally taken. Similarly for the 25% sub-sample, every fourth observation, after a random starting point, was included in the sample.

Figure 5 shows the percent difference between normal time obtained by performance sampling and normal time obtained from time study for each of the fourteen different industrial operations studied. The average difference is 2.5% with maximum variations of +15.5% for Study No. F-2 and -6.2% for Study C-4.

Figure 6 shows similar information for a sample size of 50% of that shown in Figure 5. In this case the average difference is 6.6% with a high of +14.6% and a low of -9.2%. Likewise, Figure 7 shows the results when the sample size equals to 25% of the original. In this case the average difference is 17.6% with a range of +15.0% and -9.6%.

We have observed in actual practice that some people appear to get satisfactory results by using a considerably smaller sample size than that recommended. Therefore, we have included a 50% and a 25% sample in order to compare results.

Conclusions

The conclusions of our study are presented at the beginning of this paper under the title, "What Work Sampling Can Do".

Information	Source of Data	Data for one day
Total time expended by operator (working time & idle time)	Time cards	480 min.
Number of parts produced	Inspection Department	420 pieces
Working time in percent	Work sampling	85%
Idle time in percent	Work sampling	15%
Average performance index	Work sampling	110%
Total allowances	Company Time Study Manual	15%

$$\left[\begin{array}{c}\text{Standard time} \\ \text{per piece}\end{array}\right] = \frac{\left[\begin{array}{c}\text{Total time} \\ \text{in minutes}\end{array}\right] \times \left[\begin{array}{c}\text{Working time} \\ \text{in percent}\end{array}\right] \times \left[\begin{array}{c}\text{Performance index} \\ \text{in percent}\end{array}\right]}{\text{Total number of pieces produced}} + \left[\text{Allowances}\right]$$

$$\text{Standard time per piece} = \left[\frac{480 \times 0.85 \times 1.10}{420}\right] \times \left[\frac{100}{(100 - 15)}\right] = 1.26 \text{ minutes}$$

Fig. 1. Data sheet and computation of standard time.

DAILY SUMMARY					Computation of Average Performance Index
Performance Index	April 1	April 2	April 5	Total	
100	3	6	1	10	100 x 10 = 1,000
105	13	22	9	44	105 x 44 = 4,620
110	32	21	24	77	110 x 77 = 8,470
115	48	45	17	110	115 x 110 = 12,650
120	47	49	39	135	120 x 135 = 16,200
125	27	28	56	111	125 x 111 = 13,875
130	26	13	22	61	130 x 61 = 7,930
135	15	8	11	34	135 x 34 = 4,590
140	14	15	22	51	140 x 51 = 7,140
145	8	20	27	55	145 x 55 = 7,975
150	2	10	11	23	150 x $\frac{23}{711}$ = $\frac{3,450}{87,900}$
"Working" Observations	235	237	239	711	$\frac{87900}{711}$ = 123.6
"Idle" Observations	5	3	1	9	
Total Observations	240	240	240	720	

Fig 2. Daily summary and computation sheet.

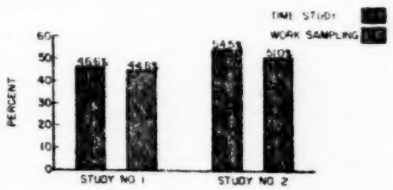
Information	Source of Data	Data for Three Day Period
Total time expended by operators (working time & idle time)	Time cards	13,650 min.
Number of parts produced	Inspection Dept.	16,314
Working time in percent	Work sampling	98.7%
Idle time in percent	Work sampling	1.3%
Average performance index	Work sampling	123.6%
Total allowances	Company Time Study Manual	15%

$$\text{Standard time per piece} = \frac{\left[\text{Total time in minutes}\right] \times \left[\text{Working time in percent}\right] \times \left[\text{Performance index in percent}\right]}{\text{Total number of pieces produced}} + \left[\text{Allowances}\right]$$

$$\text{Standard time per piece} = \left[\frac{13,650 \times .987 \times 1.236}{16,314}\right] \times \left[\frac{100}{(100 - 15)}\right] = 1.20 \text{ minutes}$$

Fig. 3. Data sheet and computation of standard time.

COMPARISON OF WORKING TIME OBTAINED FROM TIME STUDY AND FROM WORK SAMPLING



COMPARISON OF COST OF STUDY

MAN HOURS ENGINEER'S TIME	STUDY NO 1		STUDY NO 2	
	TIME STUDY	WORK SAMPLING	TIME STUDY	WORK SAMPLING
FOR OBSERVATION	3,671	224	2,886	80
FOR PROCESSING	2,936	10	2,308	8
TOTAL	6,607	234	5,194	88
RATIO	28 to 1		59 to 1	

Figure 4

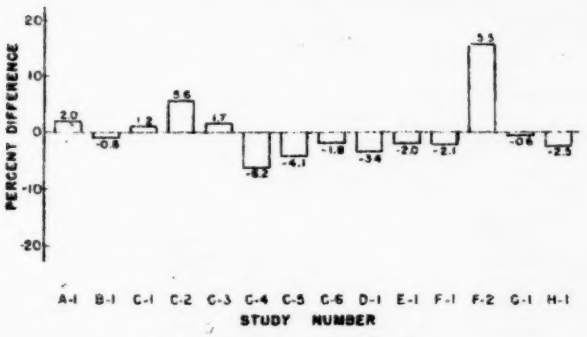


FIG 2. Results of Full Studies

Percent difference between normal time—performance sampling and normal time—time study.

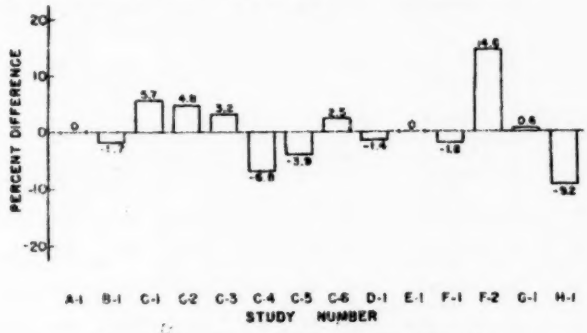


FIG. 3. Results of 50 Percent Sub-Samples

Percent difference between normal time—performance sampling and normal time—time study.

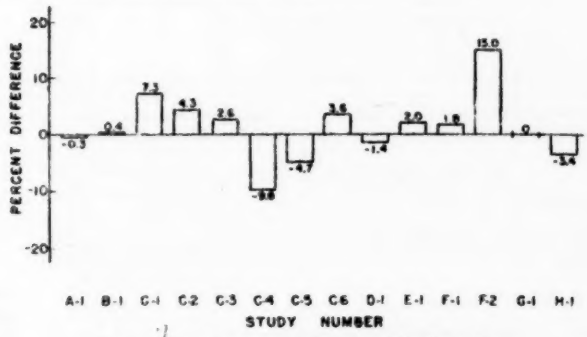


FIG. 4. Results of 25 Percent Sub-Samples

Percent difference between normal time—performance sampling and normal time—time study.

NDIX I

NITION OF SYMBOLS

level of significance

confidence level

relative kurtosis of the distribution

variation between the population mean and the sample mean

bsolute sampling error in p_m, the percent of ctual time spent on measured work

ength of the class intervals of the grouped frequency distribution

otal number of observations

umber of measured work observations

umber of measured work observations which are operator controlled

ercent of actual time spent on measured work

ercent of measured work time which is operator controlled

ample standard deviation of performance indices

population standard deviation of performance ndices

σ_s = standard deviation of the distribution of sample standard deviations

$\sigma_{\bar{x}}$ = standard deviation of the distribution of sample means

v_j = j^{th} moment about the assumed calculation mean, j = 1,2,3 and 4

π_2 = second moment about the actual sample mean

π_4 = fourth moment about the actual sample mean

$\bar{\bar{x}}$ = sample mean of performance indices

M = population mean of performance indices

Experimental Group			Operation Description	Total Actual Time	Ratio-Delay Analysis												Time Study		
					Full study				50% Sub-sampling				25% Sub-sampling						
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Company	Study Number	Number of operators simultaneously performing the operation		Minutes	Total Number of observations	Percent of total actual time spent on measured work	Absolute sampling error in p_m at 95% confidence level	Percent of measured work time operator controlled	Total number of observations	Percent of total actual time spent on measured work	Absolute sampling error in p_m at 95% confidence level	Percent of measured work time operator controlled	Total number of observations	Percent of total actual time spent on measured work	Absolute Sampling error in p_m at 95% confidence level	Percent of measured work time operator controlled	Total units produced	Normal time from time study in minutes per unit	Performance Index from time study
					(n)	(p_m)	(e)	P_c	(n)	(p_m)	(e)	(p_c)	(n)	(p_m)	(e)	(p_c)			
						%	%	%		%	%			%	%				
A	1	10	Mechanical Subassembly	13,650	720	98.7	±0.8	100	360	98.3	±1.3	100	179	97.8	±2.2	100	16,314	1.00[1]	121.6
B	1	3	Electrical Subassembly	1,350	306	89.9	±2.5	100	300	99.3	±3.5	100	150	90.7	±5.0	100	6,468	0.241	125.6
C	1	1	Cutting	460	766	74.5	±3.2	100	394	77.9	±4.1	100	197	79.2	±5.7	100	7,290	0.0424[1]	90.2
	2	1	Notching	460	766	86.0	±2.9	100	383	79.4	±4.1	100	191	79.1	±5.8	100	6,900	0.0627[1]	118.9
	3	1	Cutting	460	766	83.2	±2.7	100	382	84.3	±3.7	100	193	83.9	±5.2	100	8,061	0.0346[1]	72.9
	4	1	Cutting-Bandsaw	460	766	75.6	±3.1	100	387	74.7	±4.3	100	193	72.5	±6.3	100	6,544	0.0498[1]	63.7
	5	1	Hand Nailing	460	766	90.9	±1.6	100	384	90.6	±2.9	100	192	90.1	±4.2	100	345	0.741[1]	81.1
	6	1	Machine Nailing	460	766	75.8	±3.1	100	383	76.8	±4.2	100	191	77.5	±5.9	100	1,068	0.277[1]	84.8
D	1	4	Typing Invoices	5,550	458[2]	73.6	±4.0	100	220	75.2	±5.6	100	114	74.6	±7.8	100	2,790	1.47	99.9
E	1	7	Packaging	9,960	568	80.7	±3.2	100	298	82.2	±4.5	100	147	83.7	±6.0	100	93,732	0.103	123.3
F	1	8	Assembly	18,372	649	83.7	±2.8	100	326	83.7	±4.0	100	162	86.4	±5.3	100	201	60.7	94.9
	2		Drill Sheet Metal	2,646	540	93.0	±2.2	33.1	269	92.6	±3.1	34.5	134	93.3	±4.2	34.4	900	2.33	98.1
G	1	1	Drill, Bore & Ream Casting on Turret Lathe	4,600	300[2]	95.0	±2.5	75.8	151	96.0	±3.1	73.1	75	96.0	±4.4	69.4	2,790	1.72	109.8
H	1	4	Grinding	1,840	396[2]	68.9	±4.6	16.5	198	64.1	±6.6	48.0	99	67.7	±9.2	44.8	10,900	0.119	102.3

[1] This symbol denotes that the normal time was obtained from an established time standard rather than a concurrent time study.
[2] These companies were unable to obtain the desired 500 observations.

Explanatory Guide to Table 1

Column 1—Company Code

Companies are identified by code letter to maintain their anonymity.

Column 2—Study Number

Studies are numbered beginning with No. 1 for each company.

Column 3—Number of Operators Simultaneously Performing the Operation

In certain instances more than one operator was engaged in performing the same operation. In such cases all operators were included in the experimental group. The production of each operator was individually tabulated. In each case the operation was a one-operator task—not group work.

Example: For Company A, there were 10 employees, individually measured, performing the operation selected for study.

Column 4—Operation Description

A brief indication as to the type of operation studied is presented.

Example: Mechanical Sub-assembly

Column 5—Total Actual Time

This is the total cumulative clock time spent on the selected operation by the experimental group during the period covered by the study.

Example: 13,650 minutes were spent on the operation by the 10 employees of Company A while the study was being made.

Column 6—Total Number of Observations

The total number of observations taken in the course of the study. This includes measured work (i.e., elements of the operation which are included in the normal time), unmeasured work (i.e., productive work which was not included in the normal time), unavoidable delays and avoidable delays.

Example: 720 observations were taken during the study.

Column 7—Percent of Total Actual Time Spent on Measured Work

This represents the ratio of the measured work time (i.e., time during which elements of the operation which are included in normal time are being performed) to the actual time. The quantity is determined in accordance with conventional ratio-delay practice. Thus, the percent of actual time spent on measured work is determined by dividing the number of measured work observations (Column 21) by the total number of observations (Column 6).

Example:

$$p_m = \frac{n_m}{n} = \frac{\text{Column 21}}{\text{Column 6}}$$

$$p_m = \frac{711}{720} = 0.987 = 98.7\%$$

Where:

p_m = percent of actual time spent on measured work
n_m = number of measured work observations
n = total number of observations

LE 1
ing—Results

Performance Sampling Study

Full study						50% Sub-sampling						25% Sub-sampling					
(21) Number of measured work observations n_m	(22) Performance index from performance sampling	(23) Absolute sampling error in performance index from performance sampling at 95% confidence level	(24) Normal time from performance sampling in minutes per unit	(25) Absolute difference between normal time—performance sampling and normal time—time study Col (24)—Col (19)	(26) Percent difference between normal time—performance sampling and normal time—time study Col (25) / Col (19)	(27) Number of measured work observations n_m	(28) Performance index from performance sampling	(29) Absolute sampling error in performance index from performance sampling at 95% confidence level	(30) Normal time from performance sampling in minutes per unit	(31) Absolute difference between normal time—performance sampling and normal time—time study Col (30)—Col (19)	(32) Percent difference between normal time—performance sampling and normal time—time study Col (31) / Col (19)	(33) Number of measured work observations n_m	(34) Performance index from performance sampling	(35) Absolute sampling error in performance index—from performance sampling at 95% confidence level	(36) Normal time from performance sampling in minutes per unit	(37) Absolute difference between normal time—performance sampling and normal time—time study Col (36)—Col (19)	(38) Percent difference between normal time—performance sampling and normal time—time study Col (37) / Col (19)
					%						%						%
711	123.6	±2.1	1.02	0.02	2.0	354	123.0	±2.2	1.00	0	0	175	121.8	±3.0	0.997	−0.003	−0.3
596	124.7	±2.1	0.339	−0.002	−0.8	268	124.6	±3.1	0.337	−0.004	−1.7	136	125.1	±4.2	0.342	0.001	0.4
571	91.2	±2.1	0.0429	0.0005	1.2	307	91.2	±2.7	0.0446	0.0024	5.7	156	91.1	±3.7	0.0455	0.0031	7.3
613	122.4	±1.2	0.0562	0.0035	5.6	304	122.4	±1.5	0.0587	0.0030	4.8	151	122.3	±2.1	0.0584	0.0027	4.3
637	74.2	±1.6	0.0382	0.0006	1.7	322	74.3	±2.3	0.0357	0.0011	3.2	162	74.2	±3.3	0.0355	0.0009	2.6
579	87.9	±2.3	0.0467	−0.0031	−6.2	289	88.2	±3.2	0.0464	−0.0034	−6.8	140	88.3	±4.8	0.0450	−0.0048	−9.6
606	58.7	±1.4	0.711	−0.030	−4.1	348	58.9	±2.11	0.712	−0.029	−3.9	173	58.8	±3.4	0.706	−0.035	−4.7
321	83.3	±2.8	0.272	−0.005	−1.8	294	83.8	±4.1	0.284	0.007	2.5	148	86.1	±5.7	0.287	0.010	3.6
337	96.4	±2.1	1.42	−0.05	−3.4	170	96.2	±2.8	1.45	−0.02	−1.4	85	96.9	±4.1	1.45	−0.02	−1.4
450	121.9	±3.2	0.101	−0.002	−2.0	245	121.1	±4.5	0.103	0	0	123	122.0	±6.1	0.105	0.002	2.0
545	92.8	±1.0	59.4	−1.3	−2.1	373	93.1	±1.4	59.6	−1.1	−1.8	140	93.5	±2.1	61.8	1.1	1.8
902	98.2	±0.9	2.69	0.36	15.5	249	98.1	±1.2	2 67	0.34	14.6	125	97.9	±1.8	2.68	0.35	15.0
288	109.2	±3.6	1.71	−0.01	−0.6	145	109.0	±4.2	1.73	0.01	0.6	72	108.9	±6.0	1.73	0	0
273	100.1	±1.3	0.116	−0.003	−2.5	127	99.4	±2.0	0.108	−0.011	−9.2	67	100.2	±1.8	0.115	−0.004	−3.4

Column 8—Absolute sampling error in p_m at 95% confidence level

The absolute sampling error is ±1.96 times the standard deviation of the sample percentage. This represents the range about the observed percentage within which the population percentage can be expected to lie 95 out of 100 times. 1.96 and −1.96 are the 0.975 and 0.025 fractile values of the cumulative frequency distribution of the standardized normal variable.

Example:

$$e = \pm 1.96\, s_{p_m}$$

$$s_{p_m} = \sqrt{\frac{p_m(1 - p_m)}{n}}$$

$$e = \pm 1.96 \sqrt{\frac{p_m(1 - p_m)}{n}}$$

$$e = \pm 1.96 \sqrt{\frac{0.987(1-0.987)}{720}} = \pm 0.008 = \pm 0.8\%$$

Where:

s_{p_m} = standard deviation of the sample percentage

p_m = percent of actual time spent on measured work

e = absolute sampling error in p_m

n = total number of observations

Column 9—Percent of Measured Work Time Which is Operator Controlled

This is the ratio of "measured work time—operator controlled" to the measured work time. This quantity is similarly determined by ratio-delay analysis. Accordingly, the percent of measured work time which is operator controlled is estimated by dividing the number of measured work-operator controlled observations by the number of measured work observations (Column 21). "Measured work time-operator controlled" is that time during which those elements which are included in the normal time, and operator controlled, are being performed. Operator controlled elements are considered to be that portion of the total operation which can be influenced by the employee's skill and effort.

Example:

$$p_o = \frac{n_o}{n_m}$$

$$p_o = \frac{711}{711} = 1.00 = 100\%$$

Where:

p_o = percent of measured work time which is operator controlled

n_o = number of measured work—operator controlled observations

n_m = number of measured work observations

Columns 10 through 13

These columns are computed in the same manner as Columns 6 through 9. The only difference is that the data used are based upon a 50% systematic sub-sampling of the original complete study.

Columns 14 through 17

These columns are computed in the same manner as Columns 6 through 9. The only difference is that the figures used are based upon a 25% systematic sub-sampling of the original complete study

'olumn 18 —Total Units Produced

The actual total number of units produced by the participating perator or group of operators during the period covered by the tudy.

Example: The 10 operators of Company A produced 16,314 nits (sub-assemblies) during the test period.

'olumn 19—Normal Time—Time Study

The time required under standard conditions to perform the measured work at a normal pace but excluding any allowances. This normal time in minutes per unit was established by time study. In some instances the normal time was determined by time tudies made by the same engineer who made the performance sampling studies and in other cases the normal time was obtained rom data already available.

Example: 1.00 minute per unit is the normal time for the operation studied at Company A.

'olumn 20—Performance Index—Time Study

The performance index from time study is determined by dividing the earned normal minutes by the measured work time n minutes and expressing the result as a percentage. The earned normal minutes are the product of the total units produced (Column 18) and the normal time from time study (Column 19). Measured work time is the percent of actual time spent on measured work (Column 7) multiplied by the total actual time (Column 5).

Example:

$$\text{Performance Index} = \frac{(\text{Column 18})(\text{Column 19})}{(\text{Column 7})(\text{Column 5})} \times 100$$

$$\text{Performance Index} = \frac{(16314)(1.00)}{(0.987)(13550)} \times 100 = 121.6$$

Column 21—Number of Measured Work Observations

This represents the total number of observations in which the observed state of the operation was an element included in the normal time.

Example: 711 of the 720 observations made during the Company A study were of measured work.

Column 22—Performance Index—Performance Sampling

This quantity is the arithmetic mean of the performance ratings made whenever the observed state of the operation was measured work. Although separately recorded on the data sheet, "measured work-machine controlled" observations were added to the operator performance ratings as 100% performance observations. Measured work-machine controlled is the portion of the operation, included in the normal time, which is mechanically paced so that it cannot be affected by the operator's skill and effort.

Example:

$$\text{Performance Index} = \frac{\text{sum of the individual performance ratings}^{2}}{\text{Column 21}}$$

$$\text{Performance Index} = \frac{87901}{711} = 123.6$$

Column 23—Absolute Sampling Error in Performance Index from Performance Sampling at 95% Confidence Level

This quantity represents the range about the sample mean performance index which will include the population mean performance index 95 out of 100 times in the long run. The equation for computing this quantity is given by:

Example:

$$d = \pm\frac{s}{\sqrt{n_m \alpha}}$$

$$d = \pm\frac{12.3}{\sqrt{(711)(0.05)}} = \pm 2.1$$

Where:

- d = absolute sampling error in performance index
- s = sample standard deviation of performance ratings
- n_m = number of measured work observations
- α = level of statistical significance ($1 - \alpha$ is the confidence level)

Column 24—Normal Time—Performance Sampling

This normal time is the product of the average performance index (performance index, Column 22) multiplied by the selected time. The selected time is determined by dividing the measured work time (i.e., percent of actual time spent on measured work, Column 7, multiplied by the total actual time, Column 5) by the total units produced (Column 18).

Example:

$$\text{normal time} = \frac{(\text{Column 7})(\text{Column 5})}{(\text{Column 18})} \times \frac{\text{Column 22}}{100}$$

$$\text{normal time} = \frac{(0.987)(13650)}{16314} \times \frac{123.6}{100}$$

$$\text{normal time} = 1.02 \text{ minutes per unit}$$

Column 25—Absolute Difference Between Normal Time—Performance Sampling and Normal Time—Time Study.

As the name implies this quantity is the algebraic difference between Columns 24 and 19.

Example: Column 24 − Column 19 = 1.02 − 1.00 = 0.02 minutes per unit

Column 26—Percent Difference Between Normal Time—Performance Sampling and Normal Time—Time Study

This quantity is the algebraic difference between Columns 24 and 19, as given by Column 25, divided by Column 19 and expressed as a percentage.

Example: $\dfrac{\text{Column 25}}{\text{Column 19}} = \dfrac{0.02}{1.00} \times 100 = 2.0\%$

Columns 27 through 32

These columns are computed in the same manner as Columns 21 through 26. The only difference is that the data used are based upon a 50% systematic sub-sampling of the original complete study.

Columns 33 through 38

These columns are computed in the same manner as Columns 21 through 26. The only difference is that the data used are based upon a 25% systematic sub-sampling of the original complete study.

[2] Sum of individual performance ratings are obtained from the original data sheets.

APPENDIX II

DEFINITION OF TERMS

TOTAL ACTUAL TIME: Total work period in minutes covered by the study minus scheduled rest periods and lunch periods.

MEASURED WORK: Elements of the Operation which are included in the normal time.

MEASURED WORK - OPERATOR CONTROLLED: That portion of the total measured work which can be affected by the employee's skill and effort.

MEASURED WORK - MACHINE CONTROLLED: That portion of the measured work which is mechanically paced (such as power feed and speed) so that it cannot be influenced by the operator's skill and effort.

NORMAL TIME: The time required under standard conditions to perform the measured work at a normal pace excluding any allowances.

PERFORMANCE INDEX: For the purposes of this study, the quotient found by dividing the earned normal minutes (normal time per piece multiplied by the total number of pieces produced) by the measured work time in minutes. The measured work time is determined by multiplying the total actual clock time by the percent of the total actual time spent on measured work.

UNMEASURED WORK: Productive work which is not included in the normal time. In most studies only the repetitive elements occurring at least once a cycle were included in the normal time. For example, such elements as inspect work, line trays, record production, which occur only infrequently were omitted from the normal time. These exclusions were made to simplify the study and to increase the probable accuracy.

APPENDIX III

STUDY OF THE EFFECT OF LENGTH OF OBSERVATION TIME ON PERFORMANCE RATING RESULTS

The performance sampling technique of work measurement, which requires the observer to make ratings of operator performance based on short duration observations, raises the question of what effect the shortening of observation time has on the ability of the observer to rate performance. A limited study of this problem was undertaken.

Experimental Procedure

The method chosen for this study was to have experienced time study engineers rate a film showing several different lengths of viewing time for each of a group of different performance levels of the same operation. This provided a series of performance ratings which reflected the effect, if any, of varying the length of observation time. The film used for this purpose was a composite of the Work Measurement Film, "Dealing Cards". It consisted of three different viewing times of 5, 10, 15 seconds for each of eight different performance levels ranging from 55 to 187 percent of normal performance, based upon the national average. The sequence of scenes was randomnized, with respect to both viewing time and performance level, by the use of a random number table.

As an introduction, a scene showing an entire deck of 52 cards being dealt preceded the actual rating scenes. It served to familiarize the raters with the format of the scenes that they would be asked to rate and to provide a reference from which each observer could crystalize his own personal concept of normal performance of the card dealing operation before the rating test was begun.

The film was shown, the participating engineers were thoroughly briefed as to the purpose of the study, what they would see in the film, and what was requested of them. It was made clear that the introductory scene did not necessarily represent normal performance and that they were free to establish their own personal concepts of normal pace. Since it was the comparison between ratings and not their absolute value which was important, it was only necessary that raters have a consistent concept of normal performance.

Analysis of Data

The film was shown to fifteen experienced time study engineers at three different Los Angeles companies. The hypothesis that ratings were not affected by the length of the observation times was tested by means of analysis of variance. The results showed that the effect of differences in length of observation time was insignificant at the 95% level when compared to the inter-action between the length of observation time and the performance level being rated. This is to say that the two variables, observation time and performance level being viewed, combine to produce variations in the performance ratings which are greater than the sum of their separately produced effects.

Conclusions

No definite conclusions are to be drawn from this study and such was not its purpose. It was designed to be exploratory--to provide insight into the effect of length of observation time on performance ratings. It was undertaken on a limited scale and for only one type of operation--card dealing. It would be exceedingly dangerous to attempt to generalize the results beyond the boundaries of the study. The results indicate, however, that there is at least some basis for believing that variations in the length of observation time, within practical limits, does not have a very great effect on performance ratings.

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BOUNDING THE SOLUTIONS OF PRACTICAL QUEUEING PROBLEMS BY ANALYTIC METHODS 1/

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Introduction

This paper represents an initial effort to determine the extent to which practical queueing problems, some of which are extremely complicated, can be solved by analysis alone, that is, without step-by-step numerical computations of the Monte Carlo type. General practice in this and other fields consists in applying analysis to obtain a mechanistic understanding of the major aspects of the situation and such specific results as are practically achievable. This is done by idealizing the real problem in one or more ways, each of which yields an analytically manageable mathematical problem which differs from the real problem in a known direction. Thus the real problem is partially or completely "surrounded" by bounds obtained by analysis alone. The results so obtained are in some cases adequate in themselves, in which case the real problem is solved to acceptable accuracy. If not, they yield a deeper understanding of the fundamental characteristics of the queueing process under study and this can be used either to guide the design of operational experiments, if such experiments are considered advisable, or to guide Monte Carlo computations in such a way as to reduce the cost of getting results of adequate accuracy.

Several analytic methods, each having some range of practical applicability, are briefly described here, and the application of some of these is illustrated by specific examples. However, even a very incomplete search of the extensive literature was considered to involve a prohibitively large amount of labor, and hence many valuable methods have no doubt been missed. Rather than present a spotty and grossly inadequate list of references, it was decided to leave the compiling and maintaining of a good bibliography to some organization having adequate resources for this important and urgent job. It is regretted that this made it impossible to give credit to those whose results are used; however, originality is claimed for no method or result in this paper.

Basic Concepts

Queueing operations are here defined as those in which one or more classes of items, maintaining their class-identity, move through a network of one or more processing stations with arrival, waiting and processing times which, in general, depend on the sizes of the queues in front of the stations and may vary both regularly and stochastically with time.

Classification of items may be based on a variety of class-defining characteristics such as intrinsic properties, the statistics of arrival and processing times, the cost of delay, resultant priority rules, etc. Separation into classes is somewhat arbitrary, depending on the degree of dispersion of the defining characteristics which it may be useful to accept.

1/ This presentation is substantially the same as that given by Dr. Camp before The Johns Hopkins University Informal Seminar on Operations Research on May 4, 1955. It has been published as Chapter 17 (pp. 307-328) of Operations Research for Management, Volume II (Baltimore: The Johns Hopkins Press, 1956) and is reproduced with permission of The Johns Hopkins Press.

Also, the items may be so numerous that a "class of items" approximates a "kind of bulk material"; as will be shown later, it may be advantageous to use this "fluid" approximation even when only a small number of items are involved, because this often makes it possible to get an upper and a lower bound from a small amount of analytic labor.

Some of these points are illustrated by Figure 1, which represents an hypothetical oil-loading operation. The several grades of crude oil may be lumped together for making a rough lower-limit estimate of terminal tankage requirements, but must be kept separate for a more precise estimate. They may also be lumped together as one input of a simpler model for roughly estimating the required number of berths and other characteristics of an economic loading facility, because the queue in front of this facility may be properly regarded as the number of hours-of-work waiting to be done; however, it is necessary to keep them separate, for example, for estimating the delay of any tankers which demand a particular grade of crude. Suppose, further, that some of the tankers are engaged in a short shuttle-service between the loading facility and a nearby refinery and that this makes their arrival very regular, whereas other tankers on long-haul have arrival statistics which are approximately Poisson. In this event, an upper, respectively, lower limit on the economic loading capacity may be obtained by lumping these two classes of tankers together and assuming Poisson, respectively, regular arrival statistics for all; but, since tanker time costs several hundred dollars per hour, it will be necessary to keep these classes separate or even to subdivide them further according to their loading-times in order to make an estimate of adequate accuracy.

Returning to the definition, two additional points should be made. First, maintenance of class-identity means that each class obeys its own conservation law. This is not true, for example, in sawing logs into lumber or assembling parts into automobiles. These latter are here called <u>separation</u> and <u>agglomeration</u> operations, and the more general term <u>transition</u> operation is appropriate for the three together. This paper is restricted to queueing operations as here defined.

Second, <u>movement</u> of items may be physical or may be a conceptual movement from one state to another. As an example of the latter, units of space in an office building may exist in such states as "for rent", "rented" and "withheld for repairs", and may move from one state to another as a result of various actions; analogous remarks apply to charter ships, telephone lines, etc.

A schematic model of a queueing operation is shown in Figure 2. Fixed parameters include the possible values of holding and processing capacities for each class of items at each station, possible routes of each class of items through the network, etc. Operational variables include the sizes of the queues of classes 1, 2, .., at station 1, 2, ..; the statistics of arrivals, waiting and processing times for each class at each station, including their dependence on time and queue sizes; operational procedures; etc.

Managerial control is often representable, to useful accuracy, by a <u>feedback control doctrine</u> which specified by how much processing capacities are increased when certain queues get above specified sizes, etc. Such control

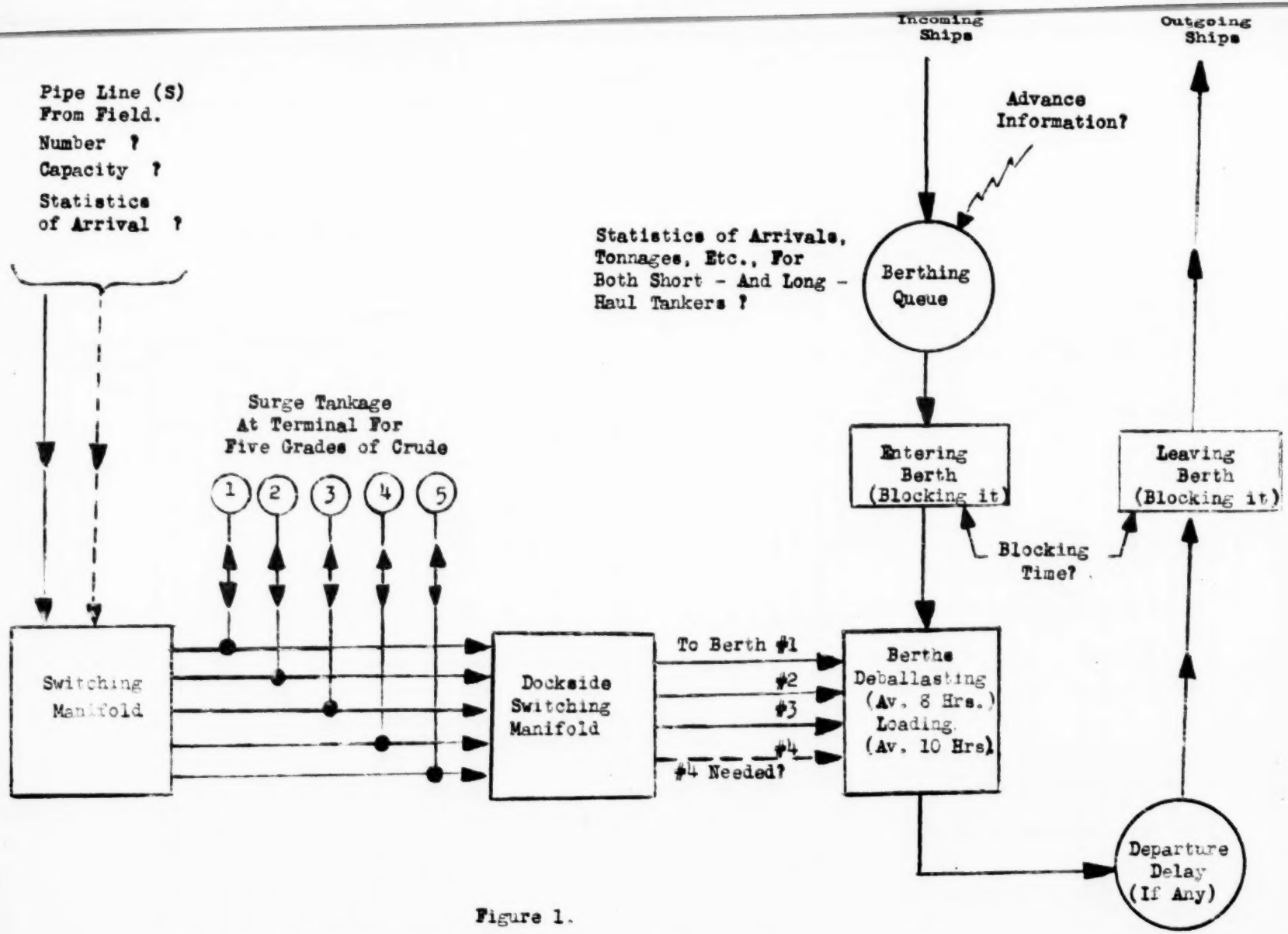

Figure 1.

HYPOTHETICAL MODEL OF LOADING OPERATION

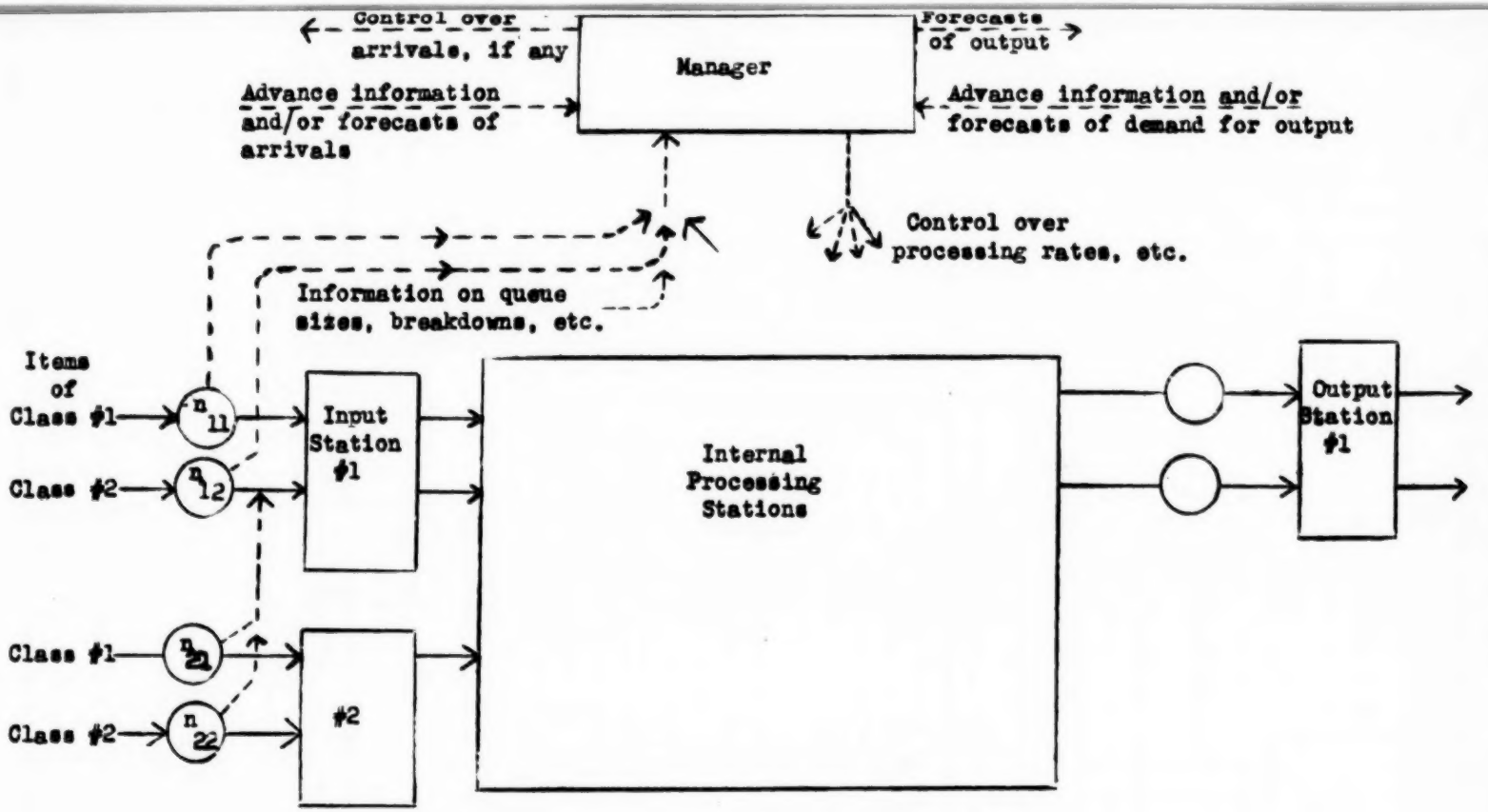

Figure 2. Schematic Model of a Multi-Station Multi-Class Queueing Operation.

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may cause interaction only between nearby stations, or influences may be exerted by distant stations or even by factors outside the network, (e.g., effect of advance information or forecasts of arrivals and demands). Regardless of these details, a queueing network is a complex servo-mechanism, usually with humans, namely the manager and his assistants, playing a fundamental role in the feedback-control loops. The basic feature of all such systems is that they can exist only in a definite though perhaps very large set of states, and that each state evolves from the previous state by a set of evolutionary rules which may be partly deterministic and partly random.

General Methods of Attack

Practical queueing problems may arise either in the functional design of a new network or in an effort to guide the alteration of the operational parameters and procedures of an existing network in such a way as to increase some appropriate measure of over-all effectiveness.

Exact solutions of such practical problems are, of course, non-existent ideals; in fact, the same is true of "exact" formulations of these problems -- approximation begins with the selection of the model, before any effort has been made to "operate" it. However, it is sometimes possible to select idealizations which err in known directions and, if this can be done in enough different dimensions, it may be possible to "surround" the real operation, partially or completely, by a bounding set of analytically manageable idealized models. This process, so familiar in physics and other natural sciences, is an essential ingredient of any practical attack.

A large part of the quantitative work on queueing networks has been based on one of the three following general methods:

1. Step-by-step numerical computation (Monte Carlo method).
2. Analysis based on servo-mechanism theory.
3. Analysis based on state probabilities.

The first of these, the Monte Carlo method, is by far the most versatile and precise, at least in the present state of knowledge. This method can deal directly with multi-station networks having quite complex evolutionary rules, the latter including distant-station interactions, advance information, etc. In each "run", it generates one of the many possible sequence of states corresponding to assumed initial conditions and evolutionary rules. By making enough runs to obtain a statistically valid sample of all possible sequences corresponding to one set of conditions, all quantities of interest can be computed; then, by making adequately large sets of runs for other conditions, the effects corresponding to these conditions can be determined. This method has only one practical drawback: for networks of the order of complexity met in practice, computation time is usually large and in many cases is prohibitive, even with modern computers; this is especially true if the combinations of several quantized values of several parameters must be explored. This practical drawback is a direct consequence of the fact that the method yields much more detailed information than is needed

or practically usable . . . one is not interested in any one of the many possible sequences, but only in appropriate statistical averages over all possible sequenc

Despite this drawback, the Monte Carlo method has great practical utility; furthermore, this is enhanced if the number of points in parameter-space which must be studied can be reduced by relatively quick analytic calculations, even if these latter have considerable error, but especially if the direction of error can be determined. This is where the other two methods, analysis based on servo-mechanism theory and on state probabilities, have rendered a valuable service.

A basic characteristic of a satisfactory queueing network is that it not "hunt" violently; that is, the manager should not find it necessary to continually issue large corrective orders but, instead, he should need only to take occasional mild corrective action when blind stochastic processes begin to get out of line. This amounts to saying that some of the feedback control should be built into the network, and that he should need to act only as an intelligent monitor. This being the case, one need not make extensive studies of models of networks that do not have such approximate stability. Furthermore, models of networks that do have approximate stability can be operated for considerable times with managerial and perhaps other feedback control neglected, going back and making adjustments whenever sufficiently large departures from appropriate conditions develop (e.g., if a queue exceeds its holding capacity or improperly becomes negative). It is often possible to perform such model operations analytically to great advantage because, although this is also a "step-by-step" process, the "steps" may be very large and, furthermore, results may be valid for whole domains of parameter space.

Servo-mechanism theory is very useful here; it establishes upper and lower bounds on expected values, including the effect of time variation, and also permits the insertion of "noise" signals appropriate to the statistics of arrivals and departures. As a practical matter, the servo-mechanism method forces one to treat discrete items as if they formed a continuous fluid; however, the direction of the error so introduced can almost always be determinec and controlled (see next section), and hence this is not a severe defect.

The method based on state probabilities does not require discrete items to be treated as a fluid (although this may sometimes be done to advantage -- see later), but it does impose limitations on the correct representation of the statistics of arrivals and departures; here again, however, the direction of the resultant error can often be determined and controlled, so that no great disadvantage accrues.

The balance of this paper is devoted to the application of these two analytic methods.

Servo-Mechanism Method

This method is so well known that little need be said about its techniques. Accordingly, emphasis will be laid on the model idealizations used and the direction of error, as illustrated by a specific although hypothetical example

taken from the oil-loading example briefly discussed earlier (Figure 1).

The problem will be taken to be to find bounds on the loading capacity required. As previously discussed, the several grades of crude will be lumped together, leading to the model shown in Figure 3.

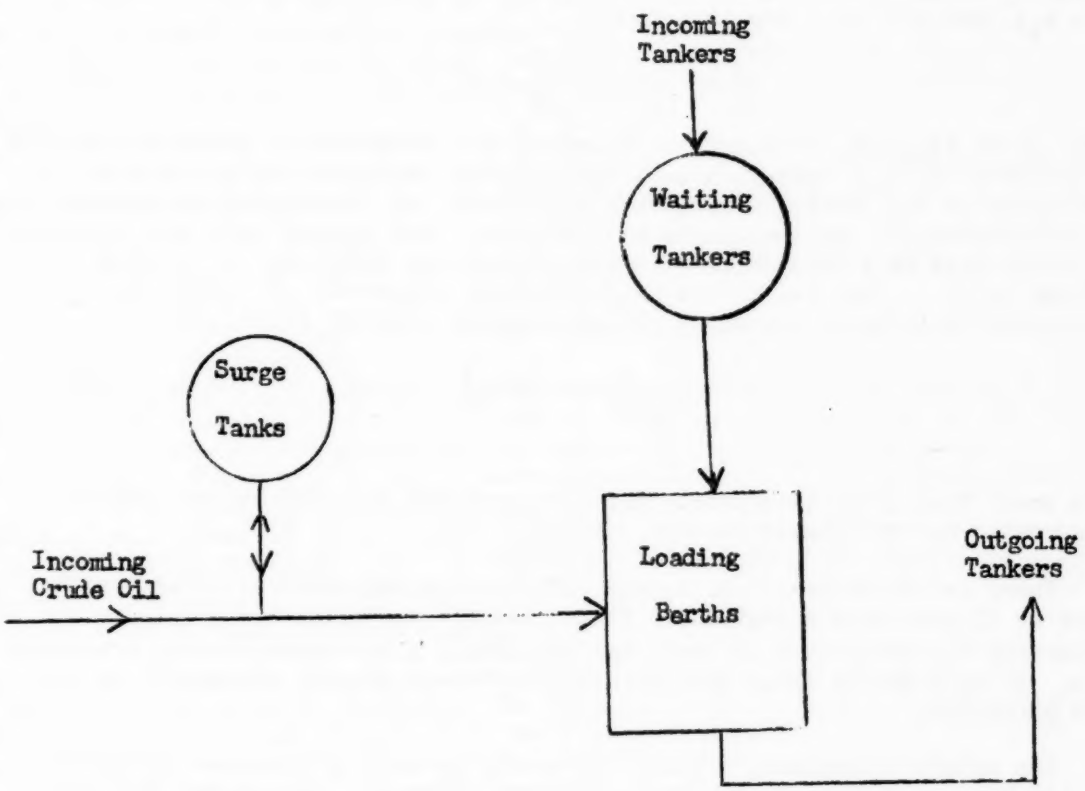

Figure 3. Simplified Model of a Part of Hypothetical Oil-Loading Operation.

It will be assumed that ship arrivals are, on the average, balanced with production; then, since the present problem is not concerned with tankage requirements, one need take no further account of the crude oil arrivals. Suppose that rough order-of-magnitude calculations have indicated that the number of loading berths required, for realistic de-ballasting and loading-times (both dependent upon maximum practical pumping-rates), lies between two and five. If the number is b, and the loading-rate of one berth for an average ship is s_1 ships/day, then the total rate has an average value of $s_1 n$ up to $n = b$ and bs_1 for larger n (n = number of tankers in the queue, including those in berth). We first ignore this saturation-effect, taking $s_n = s_1 n$ for all n. One then has

$$\frac{dn}{dt} = a(t) - s_1 n \qquad (1)$$

This is the equation governing the charging of a condenser of possibly variable capacitance $(1/s_1)$ through a unit resistor, by "voltage" $a(t)$. Fourier components of $a(t)$ having a frequency well above s_1 are highly attentuated by the "resistor", and components well below s_1 are changed only very slightly and hence lead to a succession of steady states for which the n closely follows $a(t)$. That is, if the high-frequency components of $a(t)$ are eliminated by suitable averaging, an approximate solution of (1) is

$$n(t) \approx \frac{1}{s_1} \left[a(t - 1/s_1) \right] \qquad (2)$$

This shows that $n(t)$ is approximately proportional to $a(t)$ except that it lags behind by one relaxation-time, $(1/s_1)$.

There are three principal sources of error in this result: treating the ships as if they were a continuous fluid; taking s_n to be $s_1 n$, thereby neglecting its saturation at $s_1 b$; and neglecting fluctuations in the processing rate. It will now be shown that all three of these falsify the result in the same direction.

The effect of assuming a fluid may easily be seen as follows: Whenever n lies between an integer and the next higher integer, (1) assumes that processing occurs on the extra "part of one ship", whereas processing occurs at best only on the lower integer number (actually on this number or b, whichever is lower). This obviously falsifies the result in the same direction as neglect of saturation, namely by indicating a requirement for processing capacity which is too low. The effect of fluctuations in the processing-rate is easily seen to lie in the same direction, because upward fluctuations will sometimes falsely run n negative, an impossible situation, and hence will falsely cancel the effect of downward fluctuations.

One now refines this solution in several ways. First, an approximation to the effect of saturation can be obtained by taking

$$s(n) = bs_1(t)\left(1-e^{-cn}\right) \tag{3}$$

This saturates at the proper value $s_1 b$ regardless of the value of c, and hence one can explore the effect of varying rates of saturation by varying c. Inserting this into the appropriate modification of (1), one has

$$dn/dt = a(t) - bs_1(1-e^{-cn}) \tag{4}$$

This equation is linear in e^{cn} and can be solved in closed form for arbitrary $a(t)$ and $s_1(t)$. It includes some of the effects of saturation of the processing-rate and of fluctuations in both rates, but still includes the "fluid" error. This latter can now be thrown in the opposite direction by shifting n by one unit, in analogy with the method used to bound the sum of a series by integration.

Actual operations often have several processing stations in series, and hence more nearly obey two or more coupled equations of the form

$$\begin{aligned} dn/dt &= a(n,n';t) - s(n,n';t) \\ dn'/dt &= s(n,n';t-t^*) - s'(n,n';t) \end{aligned} \tag{5}$$

These equations can be made to yield bounds on both the lower and the upper side by shifting n by one unit and, in addition, take account of the following commonly occurring effects: influence of current queue sizes on arrivals (e.g., managerial control, attraction of customers to a popular place or the reverse whereby potential customers do not join the queue if the estimated wait seems too long); similar feedback effects operating on s and s'; fluctuations and long-term time dependence in both of these quantities; and transit-time t^* from one station to the next.

These and similar sets of equations can be written for various networks and, by systematically falsifying them in various directions, bounding sets of solutions can often be obtained. The details of these analytic manipulations differ in no significant respect from the calculations commonly made in analyzing complex servo networks, and hence no useful purpose will be served in reviewing such work here. Generally speaking, the methods used do not depend for their success so much on highly advanced mathematical techniques as on establishing and maintaining a good conceptual liaison between the physical realities of the network being studied and the implications of the approximate mathematical representations of these realities, especially in the direction in which various approximations, necessary to get readily manageable sets of equations, falsify the results. For example, one of the first steps is often to neglect coupling terms so as to reduce the number of equations occurring in coupled sets, often to one equation per set. This is, of course, common practice in analyzing electrical networks, and all of the physical "intuition" so developed is more or less directly applicable to queueing networks. As an

example of this, the equivalent electrical network of a number of stations in series is an RC network with time-varying elements, driven by the arrival function, and shunted by other RC networks with time-varying networks; if "back-pressure" couplings are neglected, then all couplings are uni-directional and holding capacities may be exceeded by the queues which form; etc.

The analytic labor required is often considerable, sometimes requiring "patchwork" solutions, numerical integration, etc. Nevertheless, this labor may be repaid several times over by reducing the amount of step-by-step numerical computations required by the Monte Carlo method or, in some cases, by completely eliminating such computations.

State Probability Method

The state probability method describes queueing operations not in terms of queue-sizes as dependent variables but rather in terms of the probability of occurrence of each of the possible queue-sizes. Most work in this direction has been concentrated on the single-class single-station transition-equation, further restricted to transitions between adjacent states (i.e., transition between more distant states can occur only by a sequence of single-step transitions and hence the probability of such transitions during a short time dt is an infinitesimal of second or higher order in dt). This restricted transition equation is

$$dP_n/dt = a_{n-1}P_{n-1} + s_{n+1}P_{n+1} - (s_n + a_n)P_n \qquad (6)$$

Here $a_n dt$, $s_n dt$, respectively, are the conditional probabilities of one item being added to, respectively, subtracted from the queue during a short positive time-interval dt , given that there were n items in the queue at the beginning of this interval. The corresponding joint probabilities are $a_n P_n dt$ and $s_n P_n dt$; accordingly, the first two terms on the right of (6) represent probabilit flux into the state n from the adjacent states (n-1) and (n+1) , while the last item represents flux out of state n into these two adjacent states. The dependence of the adjacent-state transition probability coefficients a_n and s_n on n is available for the representation of the feedback effect previously discussed. These coefficients are mean values, and imply a specific kind of statistical fluctuations as will be developed shortly; the mean values themselves may vary regularly with time.

Before developing solutions of (6), it is useful to consider its relationship to practical problems in which there may be several classes of items and/or several stations, and also some limitations of (6) even in representing a single isolated station.

Since (6) makes no reference to other stations, it is clear that it must be used in a way analogous to that of a single-station equation in the servomechanism method, briefly described as follows: inter-station couplings are

temporarily neglected and (6), with appropriately adjustable values of the transition coefficients, is applied to each station separately. Then the values of the adjustable coefficients are varied until statistical balance is established throughout the network. Total cost (operation, inventory, delay, etc.) is then calculated and the remaining degrees of freedom are adjusted to make this total cost a minimum. This analytic process cannot be carried through without making several approximations and hence, as previously discussed, one attempts to control the direction of resultant errors so as to "surround" the true situation. By this process, the single-station limitation of (6) can be escaped to a considerable degree and useful results can be obtained.

There is another limitation to the types of queueing operations which can be adequately described by (6); this may be seen, in the simplest case, as follows: Suppose that a_n and s_n are independent of t, and that the network has operated under these conditions for a time long compared to its longest relaxation time, so that a long sample of the steady state is available. Necessary conditions that (6) describe this steady state to adequate accuracy include the following: first, every interval during which n has any particular value must be terminated by a single-step transition, upward or downward, with negligible exceptions; second, as readily shown by solving a simple forestalling problem, the distributions of the survival times, for both types of termination, must be approximately exponential with the same one-neper life, namely $(s_n+a_n)^{-1}$; third, the ratio of terminations upward to those downward must be approximately (a_n/s_n).

It is known in advance that these necessary conditions will not be satisfied in many cases, and hence that direct and simple applicability of (6) to practical problems is restricted. For example, there are many situations in which items arrive in groups (restaurant and theatre parties, freight cars in trains, etc.). Here one can define "item" as a party or a train instead of an individual person or freight car, at the expense of accepting a change in arrival statistics since (6) contains no direct means of taking account of the statistics of "party" sizes, except as this may be reflected by a dispersion in processing-time which happens to agree with the dispersion imposed by the form of (6). Also, arrival and processing intervals may have a greater or smaller dispersion than that corresponding to the exponential distribution discussed in the previous paragraph. In brief, it is possible to change both party size and statistics of arrivals and departures, but not independently. However, it is again possible to overcome this limitation to a considerable extent, using one or more specific forms of (6) to establish bounds, sometimes in combination with calculations based on the servo-mechanism method using several dispersions ranging from exact regularity for both arrival and processing, through exact regularity for one and wide dispersion for the other, up to wide dispersion for both.

On the positive side, (6) has the great virtue of simplicity. As will be shown, it can be solved for essentially arbitrary dependence of a_n and s_n on n, representing various feedback effects, and on t, representing various trends with time. This simplicity, together with the possibility of determining the direction and order of magnitude of the errors introduced by

using (6), combine to make it the basis of a useful method of partially or completely bounding the solutions of practical problems.

Restriction to Finite Queue-Size

The value of n in (6) is often regarded as extending to infinity, either unilaterally or bilaterally (negative values of n are sometimes used, for example in regarding backorders as negative inventory). For some purposes, however, it is advantageous to restrict n to a finite number of values, say $(N + 1)$, and, even if negative values of n are involved, to shift the origin so that the range of n is $0 \leq n \leq N$, with $P_n = 0$ outside that range, and with N taking various values appropriate to specific cases.

This restriction in no way limits the usefulness of (6), since it corresponds to actual situations: managerial control, customer feedback, finite holding capacity, or something always limits real queues to finite size, although this size may of course be very large in specific cases (in which latter case the "fluid" treatment is an excellent approximation). Thus an infinite range for n is a mathematical fiction in practical queueing problems, and this fiction should be retained when this is advantageous and discarded when disadvantageous.

The finite range of n requires that s_0 and a_N both be zero, so that there shall be no flux out of the region. The first, $s_0 = 0$, merely states that it is impossible to process an item if there are none present. The second, $a_N = 0$, states that arrivals stop whenever the queue size reaches N. This latter requires careful consideration because, while there is always an N in any real situation for which this is true, its value may not be known or, if known, may be inconveniently large.

A convenient way to handle this situation is as follows: First, select a reasonable trial value of N. Then imagine that the holding capacity (including items in process) will hold a maximum of exactly N items, spilling any item which enters when it is full into another holding capacity, and that these latter are given some kind of special handling. Then the problem can be broken into two separate parts: First, what is the distribution of items in the first queue and, second, how many items will require special handling? To solve the first problem, a_N is arbitrarily set to zero, leading to a probability distribution $P_0, P_1, \ldots P_N$ for the major queue. Then using the temporarily discarded a_N and the now known P_N, the expected rate of arrival of items requiring special handling, $a_N P_N$, can be found. In many cases this rate is so small as to be lost in other errors, and hence will be absorbed into the safety factor necessary in any realistic operational plan; if not, the calculated values of P_n, if now regarded as an approximation to the distribution of the total queue, are high for small n and low for n near N; the expected queue-size is underestimated; and so on. What to do about this should be considered aposterior for each specific case, and here it need only be noted that a measure of the magnitude of the problem, $a_N P_N$, is available before a decision need be made.

The advantages of restriction to finite n are in some cases very significant; they include the following: elimination of all questions of convergence; simple expressions for the steady-state in the case in which the coefficients are independent of time; simple methods for determining the characteristic relaxation-times, by using well known results of matrix algebra, the "fluid" approximation (see later), or recently developed numerical methods for handling large matrices and simplification of calculations involving time-dependent transition coefficients.

Coefficients Independent of Time

This case is very simple, and several specific examples are found in the literature. If (6) is rewritten in matrix form, becoming $\dot{P} = AP$, then several well known facts may be briefly summarized as follows: P and $\dot{P}$ are single-column matrices of order $(N+1)$; A is a square matrix of order $(N+1)$ and rank N or less (its determinant is zero, as indicated by the vanishing of the sum of each column, which latter conserves the normalization of the sum of P_n over n); corresponding to the vanishing of the determinant of A, there is always at least one steady-state; non-steady-state solutions have a zero sum of P_n over n, and decay like $e^{-g_1 t}$, $e^{-g_2 t}$, etc.; the decay constants g_1, g_2, --- of which there are at most N different from zero, are the characteristic values of A and their reciprocals are therefore the characteristic relaxation times; only the smallest, or the first few smallest decay-constants, corresponding to the longest relaxation-times, are of practical interest, and there are well known approximation methods for finding these constants, and the corresponding characteristic P_{ng}'s ; etc.

More than one steady state is possible so far as (6) is concerned, if the coefficients a_n and s_n have such values that zero is a multiple characteristic value of A. However, this case is of limited practical interest and hence it will be assumed that there is only one steady state. In this case, this steady state is well known to be given by

$$P_{no} = P_{oo} \left[\underset{m=0}{\overset{n}{\text{Product}}} (a_m / s_{m+1}) \right] \qquad (7)$$

Here P_{oo} is the steady state value of the probability of zero items in the queue, and is to be determined by normalization to unity of the sum of P_{no} over n.

The non-steady states can be found, provided N is not inconveniently large, as follows: One first finds one or the first few smallest characteristic decay-constants, by well known methods; the corresponding P_n's are proportional to the cofactors of any one row of A less the corresponding decay-constant multiple of the unit matrix. These non-steady state P_n's automatically sum to zero, and their normalization is therefore arbitrary. In practical problems, one will seldom be interested in the non-steady states themselves, but only in the longest relaxation-time, to estimate how long a transient state will last. In

fact, the entire case of coefficients independent of time is almost always an idealization and, as will be developed later, its principle interest is as an analytic device for studying time-dependent cases either by sudden changes in the coefficients at one or more times, or by changes so slow that the corresponding time-dependent solution may be satisfactorily approximated as a succession of time-lagging steady states. In the few cases in which the sudden-change calculations can be done entirely by analytic calculations, it may be convenient to change to a set of quantities Q_{ng} defined by $Q_{ng} = (P_{nc})^{-\frac{1}{2}} P_{ng}$ these satisfy a matrix equation of the form $\dot{Q}_{\cdot g} = -gQ_{\cdot g} = SQ_{\cdot g}$, in which S is a symmetrical matrix and hence any two $Q_{\cdot g's}$ belonging to different values of g are orthogonal.

The "Fluid" Approximation

This approximation is a practical necessity in the application of servo-mechanism theory, because this theory has been extensively developed only for the continuous case. If N is large, however, it may be a very convenient and accurate approximation in the probability method; furthermore, it may even be convenient for small N, as a quick method of establishing rough bounds. This approximation can be made in many ways, but the simplest which retains the essential features of (6) arises from regarding n as a continuous variable and replacing the second order difference operator on the right of (6) by a second-order derivative operator. If f(n) is any function of n which is expansible in a Taylor Series, then

$$f(n+1) = e^{\frac{\partial}{\partial n}} f(n) \tag{8}$$

and similarly for f(n-1). Replacing P_n, a_n and s_n by continuous functions P(n), a(n) and s(n), (6) becomes (after expanding (8) and neglecting all but the first three terms)

$$\frac{\partial P}{\partial t} = \tfrac{1}{2}\left(\frac{\partial}{\partial n}\right)^2 (s+a)P + \frac{\partial}{\partial n}(s-a)P \tag{9}$$

Although (9) is in general a complicated partial differential diffusion equation, it may be possible to approximate its solutions, numerically or otherwise, at a cost which is low compared to that of the step-by-step Monte Carlo computations which it replaces.

The case in which a and s are independent of time can be solved, far enough for most practical purposes, by the Sommerfeld phase-integral method. One first replaces time-differentiation by (-g), obtaining

$$\tfrac{1}{2}(d/dn)^2(s+a)P - (d/dn)(s-a)P + gP = 0 \tag{10}$$

Then the first derivative term is eliminated, in the usual way, by substituting $R = uP$. This leads to

$$u'/u = -(s+a)'/(s+a) - (s-a)/(s+a) \tag{11}$$

$$R'' + k^2 R = 0 \tag{12}$$

$$k^2 = (s+a)^{-2}\left[2(as' - sa') - (s-a)^2 + 2g(s+a)\right] \tag{13}$$

The function R has an inflection at all zeros of k^2 and of R itself, and R is concave toward the axis in regions in which k^2 is positive, and concave away where k^2 is negative. There will usually be only one connected region in which k^2 is positive and hence there are usually zero, one or two zeros of k^2 in the interval of interest. To find the first few characteristics decay-constants, therefore, one quantizes the Sommerfeld phase-integral between the boundaries 0 and N, or between either boundary and the one inflection, or between the two inflections, obtaining

$$\int_{k^2>0} K\,dn \cong \begin{cases} 3\pi/2,\ 5\pi/2,\ \cdots & \text{(two zeros)} \\ 5\pi/4,\ 9\pi/4,\ \cdots & \text{(one zero)} \\ \pi,\ 2\pi, & \text{(no zero)} \end{cases} \tag{14}$$

This procedure has been applied to the case in which a and s are both independent of n and here, as would be expected, it yields results in excellent agreement with the known exact results. It has also been applied to the "radioactive" case, a = constant, $s = s_1 n$, and to other cases, but no exact results were readily available to test it against.

A rough internal check on accuracy is possible along the following lines: The first term neglected in (9) is $(1/6)(\partial/\partial n)^3(s-a)P$, and this should be small, in the interval of interest, compared to the terms retained. An approximate value of the ratio of these terms can be obtained by using the approximate relation $|R'''| \simeq k^2|R'|$. According to this test, the approximate results so far obtained are reliable. $|R''| \simeq k^2|R'|$

A modification of this procedure, which would be expected to yield accurate results over a wider range, consists in making the symmetrizing transformation previously mentioned before making the "fluid" approximation. This has the effect of exactly removing a known large amplitude factor before approximating. These two procedures yield results in close agreement when applied to the two special cases previously mentioned.

Time-Dependent Transition Coefficients

This is the most difficult and also the most important case. Before discussing it in detail, therefore, two specific examples will be presented.

Since there appears to be no known general method of solving (6) if the coefficients are time-dependent, we may reverse the problem, as follows: Taking any set of time-dependent P_n's, one can look for a form of (6) which this set satisfies. One such set is the Poisson distribution, with the expected value $\bar{n}$ varying with time,

$$P_n = e^{-\bar{n}} (\bar{n})^n / n! \tag{15}$$

Substituting this in (6), one finds that it is a solution if the following relations are satisfied:

$$s_n = s_1 n \tag{16}$$

$$d\bar{n}/dt = a(t) - s_1 \bar{n} \tag{17}$$

If $(d\bar{n}/dt)$ is zero, this is the familiar steady state for the "radioactive" case in which the average arrival rate is independent of n and the average processing rate is proportional to n, and both are independent of time. Furthermore, (17) is of the same form as (1), except in two respects: first, $\bar{n}$ has replaced n and, second, $a(t)$ in (1) is the momentary arrival rate, including fluctuations, whereas it is the expected arrival rate in (17), which may vary slowly with time but contains no random fluctuations.

If $\bar{n}$ is approximately linear in t, and s_1 is independent of t, then (17) can be written

$$\bar{n} \simeq (1/s_1) \left[a(t - 1/s_1) \right] \tag{18}$$

This result is analogous to (2), and is approximately true for any $a(t)$ which varies slowly during a time of order $(1/s_1)$. One readily obtains similar time-dependent solutions for other cases, such as the binomial distribution,

$$P_n = N! p^n q^{N-n} / n! (N - n)!$$

$$s_n = s_1 n \tag{19}$$

$$a_n = (\bar{n} + s_1 \bar{n}) (N - n) / (N - \bar{n})$$

More generally, suppose that we choose any $P_n(t)$ which satisfies the general required conditions (differentiable, all positive, sum over n from 0 to N equal to 1). Then (6), written for all n from 0 to N, is $(N+1)$ linear equations for $2N$ quantities $(a_0, a_1, \ldots a_{n-1}; s_1, s_2, \ldots s_n)$; however, one of the equations is redundant, since the sum of all is zero. Thus there are N independent linear equations for $2N$ unknowns, and this indeterminancy may be resolved in many ways. One convenient way is to consider the service rates $s_1, s_2, \ldots s_N$ as known, and then to solve for the $a_0, a_1, \ldots a_{N-1}$ which, with these service rates, will yield the assumed $P_n(t)$. By doing this systematically for a representative set of $P_n(t)$ and $s_n(t)$, it might be possible to generate enough different time-dependent solutions to handle many or most practical situations. It is to be noted that adjustable parameters would be retained, so that this would not be a large set of numerical results, but rather a table of multi-parameter solutions to be used much as a table of integrals is used.

All solutions of this general class have one important property in common: They represent a slowly changing succession of steady states, lagging behind the "driving-force", namely the arrival-rate, by an approximately constant

lag-time. It is obvious that such situations will occur in practice very freque in fact, wherever the arrival rate has a time-trend which is slow compared to th longest relaxation-time of the network.

Let us now explore the opposite extreme, namely the case in which expected arrival or processing rates, or both, change suddenly from one time-constant set of values to another. If the earlier time-constant values have been in forc for a time of the order of the longest relaxation-time of the earlier network, then the suddenly changed network will have this steady state as its initial state. Now, although the coefficients have suddenly changed to new values, $P_n(t)$ will not change suddenly, but instead will gradually change, approaching the steady state of the new network in a time of the order of its longest relaxation time.

Such "patchwork" time-dependent solutions may be very useful in several ways: they yield estimates of the effect of sudden changes in processing-rates introduced as a part of routine managerial doctrine or caused by partial breakdowns; the effect of sudden increases in arrivals caused by seasonal or similar changes, and of sudden decreases caused by interruption of supply, etc.; and they furnish bounds to the effects of more gradual change.

The comparison of very gradual and very sudden changes also leads to a more fundamental consideration which suggests that the succession of time-lagging steady states may constitute the majority of cases of time-dependence which are of practical interest. To investigate this question, we need to explore the fundamental meaning of "probability of n at time t" in cases in which expected values have "long-term" time trends.

Suppose one sets himself a problem based on a very long history of the size of a queue as a function of time, this history consisting of a sequence of time-intervals in each of which n has one or another integer value. The problem is to prove or disprove that this history is consistent with the predictions of some form of (6) and, if it is, to experimentally determine the coefficients $a_n(t)$ and $s_n(t)$, with regard both to their n- and their t- dependence.

This is certainly a reasonable problem and, from the Bridgeman operational viewpoint, the whole theory is a "meaningless noise" if this problem cannot be solved, at least conceptually. Yet one immediately runs into difficulties if he attempts to apply the "ensemble" concept of probability to the problem. This is of course the very familiar difficulty which led to the famous ergodic hypothesis. If the history can be proven to be a stationary time series, then everything is simple - one can generate other "statistically equivalent" histories and then "probability of n at time t" is the fraction of such equivalent histories for which, at time t, n has any particular value. But if the series is non-stationary, how does one distinguish between "long-term" trends and a fluctuation, which seems to be necessary to generate equivalent sequences?

This fundamental subject is far beyond the scope of this paper and hence it is here assumed that "probability of n at time t" must be interpreted as "fractional time during a moving interval T, centered at t, during which n had a particular value." From the practical point of view, fractional time

is what one is interested in; that is, if f_n is this fractional time, the total delay-time is the same as if $\bar{n}$ items waited the full time T, that is,

$$T\bar{n} = T\sum_{1}^{\infty} nf_n \qquad (20)$$

If this is correct, how does one properly select T ? One first notices that there are conflicting demands on T - - - it should be "long" in order to get a statistically valid sample of the history, but should also be "short" in order to avoid smoothing out time-trends. This situation is analogous to that occurring in acoustics and other branches of elasticity theory - - - one studies the motion of an element so "small" that stresses, etc., may properly be regarded as uniform throughout; however, this element must also be large enough to be regarded as a thermodynamic system in approximate equilibrium with its environment. In this case, the resolution is very simple: for low enough frequencies (long wavelength) the variation of stresses is so slow that an element with dimensions which are a minute fraction of a wavelength is still very "large" in that it contains many molecules; and, when extreme experimental conditions are established which make this untrue, the concept of a surface stress fails and, with it, the whole theory.

Something very similar to this appears to be the case in queueing theory in that T must be long enough to give the system a reasonable chance to occupy most possible states for a good approximation to the appropriate expected times. However, this time is of the order of the longest relaxation time and hence we conclude that "time-trends" in the experimentally determined coefficients will almost always be long compared to, or at least of the order of magnitude of, this longest relaxation-time. The only significant exception to this would seem to be a case such as this: having established the characteristics of a system under steady state conditions, including arrival and processing statistics, one could have special apriori information which indicates that a sudden change has occurred in these statistics, (e.g., breakdown, interruptions of service, managerial action, etc.).

In the absence of such special circumstances, one reaches the tentative conclusion that, in most practical problems, the coefficients will have time trends, if any, which are so slow that the corresponding solution is a lagging succession of steady states, and hence approximately equal to the quasi steady state obtained from (6) by setting dP_n/dt to zero, namely (7). Thus a large part of the mathematically difficult problem of time-dependent coefficients appears to be soluble in practice, in a very simple way .... it does not materialize.

There are, of course, straightforward ways of testing this assumption in any specific case of known or assumed time-dependence: If $(1/g_1)$ is the longest relaxation-time of a network, c is any time-dependent coefficient, and if every c changes by a small fraction of itself during the time $(1/g_1)$,

$$\left|(1/g_1)(d\ln c/dt)\right| << 1 \qquad (21)$$

then the solution is well approximated by the quasi steady state. It is believed that this is the case in many practical situations.

Multi-step Transitions

As previously mentioned, (6) does not properly describe processes in which items enter or leave in parties of two or more. Such processes are better described by a multi-step transition equation of the type

$$\begin{aligned} &\cdots + a''_{n-3} P_{n-3} + a'_{n-2} P_{n-2} + a_{n-1} P_{n-1} \\ &\cdots + s''_{n+3} P_{n+3} + s'_{n+2} P_{n+2} + s_{n+1} P_{n+1} \\ &\quad - (\cdots + a''_n + a'_n + a_n \cdots + s''_n + s'_n + s_n) P_n = \dot{P}_n \end{aligned} \tag{22}$$

Analytic bounds to the solutions of this equation can sometimes be obtained by a minor expansion of the procedure described in the discussion of the "fluid" approximation. For any function expansible in a Taylor Series, one has

$$f(n + k) = e^{k \frac{\partial}{\partial n}} f(n) \tag{23}$$

Substituting the first three terms of this expansion into (22), one has a diffusion equation of the same general form as (9), and similar remarks apply, except that estimation of the error is slightly more involved. Even in cases where the "fluid" approximation is a poor one, (23) may be very useful in establishing upper and lower bounds, by shifting n by one unit.

THE DESIGN AND CONTROL OF ACTION GROUPS

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I shall begin this talk with some concepts that are essentially mathematical and conclude with remarks relevant to industrial engineering. Yet, I am neither a mathematician nor an engineer but an operations analyst originally trained in psychology. This procedure is not completely presumptuous since the road I shall take from mathematics to engineering lies in the social psychology of action groups. I shall neither start nor end on home ground, but I shall spend most of my allotted time there. The route designation of this road, which will give our journey such unity as it may have, is the term -- decision.

What can a man do to serve his needs? Basically two things: exert a force and control that force. This is true of an isolated man and as well of men acting in concert. Before the industrial revolution, the revolution of power, men commonly acted in groups to provide sufficient force to accomplish what one man could not do alone. Today a negligible fraction of society's needs for power are provided by muscles. Man's contemporary role is to make control decisions, and the revolution of control is just begun. In our modern world, men act in concert when the information handling requirements for control decisions are beyond the capabilities of individual men. It is a group of men acting in this manner which I shall call an action group.

Action Groups

The concept of an action group is closely related to the concept of task-oriented group, a term used to describe certain laboratory groups which have been the object of experimental study in recent years. All of this work has been done without the benefit of a formal definition of the concept. The work has proceeded satisfactorily in the absence of this element of formal nicety, yet it is easy to point to appreciable probable benefits accruing from a clear and relatively precise definition.

This work on task-oriented groups is a study of decision making, of information handling and of communication. As such it must have close relations to the new formal theories which are the focus of the intellectual ferment of our day. To name them, these theories are: information theory, decision theory, utility theory, and game theory. All of these new developments are fundamentally concerned with choice or decision in a formal way

just as the work on task-oriented groups is concerned with decision empirically. To bring out the relation, and thus make possible the use of the ideas of the formal theories in application to empirical studies of decision making groups, coordinating difinitions of terms applicable to groups must be given in the language of the formal theories.

Following a beginning attempt in this direction made by the author (2), my former colleague Duncan Luce* applied his mathematical talents to the problem and developed a definition of the concept which I am here calling an action group. This definition is framed in the language of game theory and I shall start by borrowing a key idea from Luce's definition.

For this definition we need the concept of a game in the sense of von Neumann and Morgenstern's (3) theory of games. I shall state this informally, but a rigorous treatment would be possible. Let us consider a collection of individual persons each of whom is faced with a number of mutually exclusive courses of action. Each person must choose and execute one of his available alternatives. In general, the choices concern prescriptions for action or decision rules covering every situation that may arise from the start of interaction until the final outcome is reached. The decision rules are called strategies. As a result of their employment there will be various outcomes for the various participants -- they may gain or lose varying amounts. The result for each person depends on his choice of strategy and also, in general, may depend on the choices of the other players in the game. Since the players will have preferences among the possible outcomes and success by one may hamper success by another, a game is a formal model for conflict of interest situations.

Thus far, the concept of a game seems a strange one to use in defining an action group since the conflict of interest which is essential to all but degenerate games is the antithesis of the commonality of interest that seems to be central to the intuitive notion of an action group. However, if the game model is a reasonable model for human interaction, and it seems to be, then we must find a way to resolve this difficulty. The key to the situation is that although it is true that conflict of interest (at least potentially) is characteristic of all groups, a group becomes an action group by virtue of constraints on the possibility of conflict. This notion can be expressed in a form that brings out its relation to game theory.

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*Luce, R. D., on the interaction of suboptimization and communication structure in group performance. Paper read at the Annual Meeting of the American Psychological Society, San Francisco, Sept. 1955.

As we said earlier, each player in a game has preferences among the possible outcomes of the game. Under conditions established in the theory of utilities a person's preferences over a set of risky outcomes can be expressed numerically so that the preferred one of two outcomes has the larger expected utility. With this characterization of its structure, a game in normalized form is mathematically a set of real-valued functions, one for each player, the variables of each function corresponding to the choices available to the corresponding player. These functions are called the pay-off functions of the game.

Now let us introduce into our consideration a person who may not be a player, and hence unable to influence the outcome by a strategy choice, but who nonetheless has preferences among the outcomes. He may have means other than strategy choices by which he can influence the interaction of the players and thereby influence the game's outcome. We shall call this person the evaluator and, assuming that his preferences can be represented numerically, he has a pay-off function. The evaluators pay-off is a value imposed on the game called the evaluation. The introduction of the evaluator and the concept of a game with evaluation is a contribution by Luce of which we shall make use.

Luce proceeded to define a task-oriented group (action group) as follows:

A group of persons is an action group if and only if:

1. The group constitutes a game with evaluation;

2. Each of the group members knows the evaluation function (knows what the evaluator prefers);

3. Each member of the group is motivated to modify his individual preferences in such wise as to maximize the evaluation function.

This definition is an important step forward but it has a number of drawbacks. It does not take explicit account of the possibility that an action group may be in a game but not coterminous with it. It requires knowledge of the evaluation function whereas a requirement for some degree of conformity of behavior seems more pertinent. It states as a defining condition a "motivation to modify individual preferences" which is a conception that itself demands explication to be useful. This third drawback was remarked on by Luce.

The thought that an action group may be in a game but not coterminous with it suggests considering another concept from game theory, the concept of a coalition. We shall not use

this concept in our definition, but our explication of "action group" will have an important relation to the coalition concept. This relation may be useful in the study of action groups, and if so will be an example of the kind of advantage we hope may accrue from our attempt at formal definition.

Let us consider the full set of persons in a game as divided into two groups and let the game be evaluated with respect to only one of the two groups. That is, we consider that the evaluator has preferences among the outcomes of the game so far as the pay-offs to the one group are concerned but is indifferent so far as the pay-offs to the other group are concerned. A requirement on the first group that its decisions produce the outcome preferred by the evaluator will be defined as a task for that group, and consequently we shall call that group the evaluator's group.

The evaluator whose preferences serve to define the task need not be a real individual person. He may be a fiction introduced for the purpose of defining the task. For example, this so-called person may be a device to represent a valuational consensus of the group itself. By this means we may cover the case of a group goal set by an agreement reached within a group which may come to dominate the originally conflicting individual goals. Moreover, since we do not exclude the possibility that the task pay-off function may coincide with the pay-off function of one of the players, it is possible that one and the same person is a player and is the evaluator. The role of a boss may be characterized in this way.

Using the definition of "task", based on the concept of "evaluation", we define "action group" as follows:

A group of persons is an action group if and only if:

1. Its members are players in a game with evaluation;

2. It is included in the evaluator's group.

3. To some non-zero extent, the members of the group choose their strategies in accordance with the task rather than by individual preference.

We shall compare action groups as given by our definition with the concept of a coalition as given in game theory. We shall find that an action group may be a coalition, but generally will not be, and that a coalition is kind of idealized form of action group. In connection with this comparison we shall offer a definition of a type of group which lies between action group and the rational coalition concept of game theory. Let us describe the rational coalition concept.

A coalition in a game is any set of players who so modify their individual strategies that the expected pay-off to the group is larger than the sum of the expected individual pay-offs would be without the coalition. Rationally, coalitions will tend to form and can be maintained provided utility is transferable among the players in the coalition and side payments are made among them. Stability of coalition structure requires that the algebraic sum of the pay-off for each member and any side payments received or made by him is no less than he could get for himself by other actions.

There may be any number of players in a coalition ranging between the two degenerate cases of a single player and the total set of players, and we may even formally admit the null set as a coalition.

It is now important to emphasize one aspect of the difference between being a player in a game and being a member of a proper coalition. Fully rational behavior is not necessary for a man in order that he may be properly described as a player in a game. It is only the strategy choices which are given by what is known as a solution of the game which are (according to an established criterion) rational -- actual behavior may depart from the requirements of a solution. To be a member of a coalition necessitates fully rational behavior since the comparison of pay-offs which is used in the definition of a coalition is given in terms of solutions.

The rational form of the coalition concept is effective for normative theory but falls short of the requirements for a descriptive theory. Therefore, I propose to introduce a modified concept which, in distinction from rational coalition, I will call heuristic coalition. A heuristic coalition is any set of players in a game who modify their individual strategies so that the pay-off they <u>believe</u> the group will get is larger than the sum of the individual pay-offs they <u>believe</u> they could get without the coalition. The difference between the two kinds of coalition is that the former is based on mathematical expectation and the latter on belief. Note that it is possible for these to coincide, but that belief covers more ground; thus when all coalition members' beliefs are rational, a heuristic coalition is a rational coalition.

The difference between an action group and a heuristic coalition is that the former depends on an evaluation and the latter does not. If the evaluation for an action group coincides with the beliefs of its members then the action group is also a heuristic coalition. Further, if the beliefs are veridical the action group is a rational coalition. Let us consider these facts as they bear on the role of the evaluator.

The evaluator is some person who may or may not be in the action group and who may or may not be in game but who has preferences among the possible outcomes of the game insofar as they affect the pay-off to the action group. This person has a pay-off function which is an evaluation of the game, and independently of whether he is in a position to make strategy choices in the game let us suppose he has other means by which he can affect the behavior of the action group but does not have other means by which he can affect the behavior of players who are not members of the action group.

The evaluator has the problem of the design and control of the action group. The first requisite of a solution to his problem is that it must maintain the integrity of the group. There are two antithetical ways he can approach this problem: 1) he may treat the behavior control problem directly by imposing restrictions on strategy choices that often must be maintained by the promise of invoking sanctions (non-transferable utilities); 2) he may treat the problem indirectly by seeking to control the beliefs of the group members so that the group becomes a heuristic coalition acting in accordance with his evaluation. The second possibility is the more attractive one if it can be successful since it avoids a potent source of tension. However, there are further difficulties with this approach.

There are two principal bases on which an attempt to control beliefs may be made. These two approximate what we would ordinarily call education and propaganda. By suggesting these terms I do not intend to contrast techniques, although in practice this contrast will usually be found. Rather, I intend to contrast the relation between fact and the content of the persuasive effort in the two cases. In either case, the evaluator attempts to convince the group that acting in accordance with his evaluation will give the group the character of a rational coalition. In addition, in the educational case, the evaluator knows that action in accordance with his preference will make the group a rational coalition; in the propagandistic case he either does not know this or knows it to be false. This is a very severe characterization of the educational case since it requires a full knowledge of the game structure on the part of the evaluator. Game theory is not in a satisfactory state at present to give fully dependable guidance. Not only are there practical difficulties in solving problems, but there are several non-equivalent equilibrium theories no one of which is generally considered acceptable.

In part because of this unsatisfactory state of affairs, and in part because of other human limitations of any person who is in the position of the evaluator, the design and control of action

groups in practice will be a mixed process. Some resort to sanctions will be used at least as a safeguard against the failure of other efforts to maintain the group integrity. The major effort will be to control beliefs, and since an educational effort by our strict definition will rarely be possible, the best that can be done is for the evaluator to substitute for certain knowledge the best founded belief he can attain and to attempt to persuade the group members to accept his beliefs.

An important promise that the concept of rational coalition holds (a promise that is far from realization at present) is that it will constitute a norm against which to judge the potential stability of an action group. For <u>if</u> an action group is a heuristic coalition and is <u>not</u> a rational coalition, it is making its decisions on the basis of beliefs that are false and the facts of experience have a nasty way of changing beliefs and the direction of change is most commonly toward the truth. Thus, a heuristic coalition that is not a rational coalition has an inherent instability.

Group Information Handling

Beyond the necessity for maintaining group integrity, the evaluator's design and control problem concerns the efficiency of the group's internal functioning. This is primarily a question of the management of information handling. But before restricting our consideration to pure efficiency problems it will be well to point out that the process of maintaining group integrity may also depend on handling information. Our definition of action group requires that the group have a task and behave to some extent as the task requires, but it does not demand that the task be known to the group. Action can go on in the absence of this knowledge and usually does go on when such information is incomplete or somewhat vague. Yet, gaining it and using it as a basis for action is a common concern of group members. Thus we have the young business executive who poses to himself or to a management conference the question, "What business are we <u>really</u> in?" or the subordinate military commander who on receiving an order wonders, "What is the old man thinking of?"

Because of these natural human tendencies, an evaluator who does not take steps to make certain that the group for which he defines the task knows that task is, in effect, imposing the problem of task definition on the group. This is an added task which derives from the task he intends to impose, and a lack of knowledge concerning it, whether he wishes it to or not. It is not difficult to produce examples of task problems for which a definite completion criterion can be proved to exist but for which the actual definition of the criterion is so difficult to

develop that a group given the task of attaining the criterion by being told to get the best possible answer will not have a definite goal at all. In such a case it may be expected that the group will adopt some heuristic device such as group agreement to give a quasi-definition of task completion. Furthermore, the need to get group agreement then imposes a second additional task. Goal definition and goal agreement as tasks may then be worked on simultaneously with the basic task and even come to dominate the later. In such a case the situation is closely parallel to the "human relations problems" which social psychologists have so often used in the experimental study of group behavior. These problems are of great intrinsic interest but they lie outside our present principal concern.

The task for an action group is to attain a specified outcome by making decisions and implementing them. Thus, given the task we know for sure only an endpoint. To describe group action adequately we need to know other things such as initial conditions. Theoretically we know these things from the game which is the context within which the group acts. In practice we can usually give only a cursory description of the context as a game. However, some features of this situation are so nearly universal that to describe them is to characterize action groups empirically even though they are not required characteristics according to the definition.

One such feature is that the group has information inputs. A second is that this information is at least partly pertinent to the decisions that are to be made. Thus, in addition to the decision making function, the group has an information acquiring function. This may be a quite passive process in that by some means requiring no effort on the part of the group the input is provided. On the other hand, the group may find it necessary to make a major effort of data collection.

Unless the information relevant to each decision is input to the group at the same point at which the decision is taken, the information must be handled from point to point through the group. I will assert that it is the effectiveness of this process that is the principal determiner of the efficiency with which a group accomplishes its task.

Let me take a very simple and well known example to illustrate my point. Consider the game of Contract Bridge. Partners in Bridge constitute an action group in our sense. Each one has an information input acquired by looking at the cards he is dealt. The role of the evaluator is taken by an implicit agreement between the partners to bid and make the greatest number of tricks the deal will support. Neither player knows

the other's hand initially but such knowledge is relevant to decisions about bidding. The systems of Bridge have been devised principally to expedite the transfer of this information and the efficiency of a Bridge partnership using a particular system depends directly on the effectiveness with which the system as they use it handles information.

In general incoming information will not be in the most readily usable form for making decisions. It needs to be processed. The distinction between raw input information and information processed to support decision making has been recognized traditionally by calling the former either data or simply information and the latter intelligence. Between input information and intelligence for decisions there may be many steps of processing and each such step will necessitate decisions. Therefore it is not only the output of action that requires decision but every step taken to support the action decision is itself a decision step. When we speak of a strategy choice for individual members of the group, decisions of both types will generally be involved.

Information for action will be called first level information. The decisions about processing on this level are themselves based on information which will be called second level information. This is data about the status of first level information at a given time, that is, about who knows what now. Second level information is sometimes not a sufficient basis for first level decisions. Consider the case in which it is perfect throughout the group. Each man knows exactly what every other man holds. His choice should then be to send to someone who needs but does not have some information which he has. But there may be more than one such potential receiver and there may be someone other than himself who can make the same contribution. If both send to the same person a useless duplication has occurred, and worse, another man may be left wanting unnecessarily. Coordination is lacking. The sender can be assured of making a proper choice only if simultaneous sending by others is predictable. Such predictions can be made if information handling is organized and he knows the organization. Information about organization will be called information on the third level. It is information about who will do what and derivatively about what information distribution situations may be expected.

There are several different kinds of information handling functions. I have just mentioned the question of to whom to send. This is a reference to the routing function. There is also the question of what to send and this implies a filtering function. Filtering, perhaps, requires and gets greater attention than any other process applied to information. It

is the principal operation that makes intelligence out of raw data. It is the function served by digests, abstracts and summaries. It occurs in less obvious ways every time the output from a man is selectively less than the input to him in an informational sense. It is interesting that the reverse is true from the standpoint of energy. A man who is a filter for information is simultaneously an amplifier energy-wise. Such selective amplification is most useful when incoming information is not perfectly reliable and the filter produces an output of increased reliability.

Next we have the coding function or the problem of how to send. This is an area of current intense interest due to the development of information theory which has been most outstandingly successful in its treatment of coding and the relation of coding to channel capacity. The importance of coding is obvious even in simpler ways such as is made evident when two persons try to communicate and neither knows the language of the other. It is clear that coding will have strong implications for the efficiency of action groups.

Finally there is a timing function. Information is perishable so timeliness of sending is essential. The useful lifetime of various items of information differ and the rates of decay may also. Efficient handling will require the use of priorities to establish order of sending. Timing and routing in this connection are often involved in an intimate interaction and the joint problem then posed is usually called a scheduling problem.

These four functions in various interacting combinations are what the evaluator must organize by designing and controlling the group. What means are at his disposal to develop efficient organization? Assuming that his measures for maintaining the integrity of the group are adequate, the members of the group will be motivated appropriately. Therefore, if a feedback of knowledge of results is provided, the basic conditions for learning better and better procedures will be met. This is the kind of phenomenon in action groups which has been called growth in organization--a somewhat valuative characterization, but the analogy is striking. The important point in this connection is that the evaluator cannot treat the organization like Topsy. Growth must be a guided and controlled process. Changes of this sort will surely occur but to be useful these changes must be directed changes. The organizational devices I will be discussing shortly can realize their potential of effectiveness only if they are supplemented by a training program in their use.

The capacity for learning is a component characteristic in systems including human beings. We have observed that it can be managed and use made of it after the human components are in the system. In addition, learning has acted on the human components before they entered the system or group, and as a result the group members bring with them a store of habits, skills and attitudes of which the evaluator may make use. Consider coding, for example. Its quality may be judged by the probability that a message sent by one person is correctly interpreted by its receiver. If the group members all have learned the same language before joining the group the coding function will be handled well without any particular attention to otherwise organizing it and coding problems will be at a minimum.

A more direct organizing technique is to provide rules of behavior. It is theoretically possible to completely organize a group by writing such a complete rule book that every possible situation that can arise for each member of the group will be covered by an action to be taken by the person in the situation. It is clearly impractical to go this far with almost any problem the evaluator may have. For one reason, such a rule book would likely have to be so massive, contain so much detail, that its use would pose a training problem of intolerably large dimensions. Moreover, if this were done the necessity for decisions by group members would be eliminated except for decisions as to what rule is to be applied. Rule applicability decisions would be routinized through training and thereby the role of the group members would be reduced to recognizing situations and automatically applying the rules. Unless the perceptual capabilities required for recognizing situations are those natural to ordinary human skills (allowing for training) and are otherwise quite complex to implement, the human components are not being well utilized and would better be replaced by an automation of the process. It is quite true that many industrial operations in current practice require essentially no decisions of the operator except those involved in the routine use of his perceptual capacities and an automatic action triggered by the perception. To replace these jobs by machine operations is a challenge to the engineer, at least in part because such jobs make poor use of the whole man. To do so is no easy engineering task, for the human perceptual apparatus is an information handling machine of great complexity and subtlety, and one which is at present very imperfectly understood. The engineer must study the process with the psychologist's help so that he can design sensory devices, equipment to process inputs from the sensory devices, and motor devices to take the actions required. The result will be socially justified for the reasons just cited and the probability that it will also be justified economically is increasing. The cost per unit of information communicated is decreasing and

is likely to continue to decrease for a generation. As we learn more and more about the design and control of action groups the completeness of the rule books we could write will become greater and greater and as a direct result, more and more of society's needs for information handling will become amenable to automation. We shall return to this point in the final section of the paper.

Experiments on Action Groups

My colleagues, R. Duncan Luce and Josiah Macy, Jr., and I have studied action groups by laboratory experimentation (1). I shall briefly describe some of this experimentation and its results with a view to showing how it bears on future developments in mechanized information handling.

We concentrated on information handling operations internal to the group, and in particular, on the organization of routing functions. To do so, we instituted rigid experimental controls of the factors we were not studying in order to bring out sharply the features we intended to study. This is the reason we chose to study groups in the laboratory rather than in the field. We accepted the consequence that the face validity and ease of application of our results would be weakened to gain the advantage of precision of control and analysis that is possible only in the laboratory.

We used five man groups provided for the purpose from enlisted military personnel. They were unselected except that men with low GCT scores were excluded. The situation was designed to exclude competition within the groups and to provide all necessary inputs of information without special acquisition efforts by the members of the group. The task was very simple, requiring no filtering or recoding, and timing was controlled by providing a signal for all persons to send which was triggered when the last person was ready to send. Routing choices were left open except as we will note later and except that all messages were required to be single address. Since each man sent his first message at the same time and likewise his subsequent messages, each such occurence was called a group act. The task objective was to distribute five items of input data, given one to each man, so that each man wound up with all five inputs in his possession, using as few group acts as possible. The evaluator was, of course, the experimenter, and his preference was made known to the group by instructions which advised the members of the group of the exact minimum number of group acts with which the information distribution could be completed. Thus the group had a clear and explicit goal and since each man knew how many messages he had sent, he also knew how nearly the group had come to reaching the goal.

Almost no organizational information was provided and no provisions for developing such information during the course of repeated trials were permitted. Local second level information was naturally provided by the fact that each man knew what he had sent and to whom, and also what he had received and from whom. In this way the possibilities for developing organization depended either on the rational use of the available second level information or on trial and error learning. The experiments provided data on these aspects of organizational growth and, in addition, certain rules varied from group to group were imposed on routing choices so that their effects could be tested. These rules were in the form of an imposed communication net which is a set of rules in the sense that it establishes the permissibility or impermissibility of sending for all pairs of persons in the group. The communication net is a readily managed way of imposing routing rules since it need not depend for its implementation on any person remembering the rules and thus it is easily made inviolable.

The experimental results demonstrated that our subjects were able to make rational use of local second level information and that they improved in this respect with practice. They also showed that the subjects learned to make effective choices in some cases when local second level information could offer no basis for a choice and that this learning was contingent on a knowledge of previous trial outcomes. There was a very strong interaction between rationality and learning as elements in organization and the imposed communication nets. I shall not go into detail about this matter, but only point out that the phenomenon is explained by the relation of the second level information provided from the flow of first level information in the situations which can arise within various networks to the requirements for an effective information handling strategy choice in those same situations.

In summary of our conclusions from the experiments I will state:

1. Information is just as necessary for the control of information handling as it is for the control of action;

2. Local second level information will be automatically available for the control of first level information and can be well used up to the limits of its utility for this purpose;

3. Global second level information as opposed to local information is available only if provision is made for its transmission and even if it is complete at all times it is not a fully adequate basis for information handling decisions;

4. Rules, especially a communication net, which are imposed in the attempt to organize information handling strongly affect how well second level information can be used;

5. The possibilities of organizational growth by learning are vitally influenced by the organization imposed by rules;

6. When rules have been imposed, second level information may be supplemented by third level or organizational information and effectiveness may be achieved more readily by this means than by relying on second level information alone.

Not all of these conclusions can be considered firmly established by our experimental work, but they are all at least strongly suggested by this work. For emphasis, let me repeat the salient point; if information is to be used effectively for action, its use must be guided by further information.

Implications

Action groups, either purely human or as man-machine systems, are the means for accomplishing society's necessary work. They must do their job without delay regardless of how inefficient they may be. We have seen that their efficiency depends fundamentally on the provision and use of information for the control of action. We have been able to sketch some of the features of the process of using information for this control function. Consequently, the most fruitful direction in which to move in seeking enhanced efficiency is clear.

In the absence of the total information relevant to control, work must go on using whatever information is available. The most common device used to get on with the job under these circumstances is to develop a lore of the operation, to depend on tradition or uncontrolled experience to fill the gap. The danger in this procedure is that operational lore, being an integration of experience rather than current intelligence, sacrifices sensitivity in order to gain stability. Stability carried to the extreme that is so often connoted by the term tradition is stagnation, and like the rose, by any other name it smells. In the future, tradition must more and more be replaced by current intelligence.

The time is ripe for an explosive development in the use of information. Since efficiency can be improved through proper use of information with no increase of facilities other than for information handling, there is a double economic reason to suppose this development will proceed extremely rapidly. Not only can efficiency be improved, but information can replace materiel handling and storage facilities. Let us consider an example or two.

As, electronic engineers create more subtle designs their demands for precision in components increase sharply. The manufacturer must supply the new demand in a competitive market. It is very expensive for him to redesign his operation and retool to produce the item, let us say resistors, with the required precision. So he uses information provided by a selection operation following his standard production method and is able to meet the demand with no change in production facilities.

Highway congestion is currently a major national problem, especially in urban areas. The only attempts at a solution now enjoying major support are programs for building more highways. This is undeniably a good solution in terms of the benefits produced, but it is an enormously costly one. Improvements in control measures are also being made, but these are picayune by comparison. They fail to make a real dent in the problem because they depend so little on information about the current state of traffic flow. Control is not based on operational intelligence. The time should not be long coming when traffic control computers provided with a very large capacity for sensing traffic conditions and processing this information for control purposes will remove us from the annoyance of signal systems insensitive to our needs.

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EXECUTIVE DEVELOPMENT
- IN THE FIRST PERSON

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To a profit-making concern, a good executive is as valuable as a good product. Hence, many concerns are getting around to spending as much on executive development as on research and product development.

But executive development suffers from the fact that everybody knows exactly how to develop an executive. Hence, what is done ranges from the study of arts and classics to training in the techniques of reading, writing, and public speaking. Some employers train future executives in techniques of organization and management, others concentrate on training their executives exclusively in human relations, still others force would-be executives to read and debate cases, no matter what the cases may be about.

If one looks at the vast variety of sure-fire ways we have for developing executives he is reminded of William Allen White's statement that: Every man is absolutely sure he can do three things as well as anyone else: "Rock a baby", "poke a fire", and "edit a newspaper." We might add a fourth: "Develop an executive".

Executive development suffers also from the fact that it is viewed almost exclusively as a third-person process. Those of us who can look back in the year 2,000 will, I suspect, conclude that executive development in the first person, was the more productive of results. In the meantime, however, the bright-eyed and bushy-tailed industrial engineer will likely be puzzled. He looks at the variety of activities carried on in the name of executive development and asks: What does a guy do if he wants to climb the ladder?

My comments are designed to help answer this question. I propose to do what a good industrial engineer does with a materials handling, a job standards, or any other problem. I propose to break the substance of executive development down into simple, component parts and with these parts develop an answer. In short, I propose to do three things:

First, I will state three premises on which executive development - in the third person or first person- should logically be based.

Second, I will describe four fields of knowledge that would-be executives must recognize and then comprehend.

Third, I will describe five habits that the would-be executive must develop.

Premises for Development

As early as 1916, Henri Fayol, the noted French student on organization and management, showed how, as the individual rises from workman, foreman, shop manager, and department head to the rank of general manager and above, the "technical" abilities that helped him to rise become steadily less valuable. He made clear that the individual who climbs the managerial ladder need not forget the skills that helped him up the first few rungs, but he must acquire new skills he didn't have, or he won't climb higher.

Hence, the first premise is that the individual who would become an executive must comprehend, as he goes up step-by-step, new skills he didn't earlier need - and learn to relinquish those in which he is expert.

What are these new skills or abilities? The accompanying chart entitled "The Emerging Need for Management's Lore" suggests, in graphic form, the substance of what Fayol described as "administrative abilities". In short, it suggests these administrative abilities come from an understanding of those fields of knowledge depicted on the right of the chart.

The second premise is that getting things done through other people, whether the task be undertaken within a church, a university, a bank, a manufacturing plant, or a municipal highway department, is essentially the same process. And the abilities required to carry out this process can be identified, defined, and understood.

The third premise is that individuals who succeed as executives usually display certain traits that can be identified, made understandable, and developed.

There are those who have contended that executives are born, not made. The very idea of executive development contradicts such a contention. But we are at the stage in developing our processes of executive development that we must rethink why we believe executives can be developed and how it can best be done.

These three premises - (1) that progress throughout the working life span requires the development of new and different abilities, (2) that the content of administration can be broken down, defined, and learned, and (3) that those habits that distinguish the successful executive can similarly be identified and developed - lay the foundation for that rethinking.

One accepts the first premise when he asks: How can I, an industrial engineer, equip myself for an executive job? The question implies your recognition that you are a specialist, that you seek an opinion as to how you can develop the skills required for managerial tasks. Let me turn then to the application of the second premise that the content of administration can be broken down, defined, and hence, learned.

Areas of Knowledge Inherent in Administrative Abilities

There are, I believe, four identifiable fields of knowledge that make up the content of Fayol's "administrative abilities."

One may question whether administration is yet a science. But one can not deny that there is an organized and rapidly growing body of knowledge, which fills many books and articles, as to how one can best organize, plan, direct, and control the efforts of human beings to a common end.

The individual who is making the "bridge over" from being a 'specialist' to becoming a generalist has had little time or occasion to explore, let alone master this expanding body of knowledge. If he is to succeed as an executive he must master this area of knowledge. He may do this by being taught in "programs" or "courses". More likely he will master this knowledge, almost consciously, by watching others, by reading and thinking. Whichever course he chooses, this field of knowledge is definable. It is clearly staked out for he who would develop himself.

Second, the specialist growing up needs to learn much about those other specialties that are equally essential to making an enterprise run. The research chemist who is being promoted into executive rank need not become a specialist in the selling of the enterprise's products. He does need to learn enough about the peculiar characteristics of the sales function to be able to "understand" the salesmen. This much he must know if he is to perform the executive's unique task of catalyzing the specialized contribution of the salesmen with the variety of individuals that make up the enterprise.

Third, the industrial engineer, or any other specialist, who wants to climb the managerial ladder, must broaden himself. What

does this loose, trite saying mean? It means that he has to understand the labor unions with which he must deal, the government that regulates, taxes, or controls the enterprise in many ways, the communities in which the company's plants are located, and the whole society of which his enterprise is a part.

The would-be executive can not get ahead by having an expert knowledge of things, of books of account, of mechanical processes or of successful sales gimmicks. He must understand the customers, the workers, the bankers, the civic leaders, and the institutions, and the economic, political, and social forces with which the enterprise must deal. He must be capable of walking up to the life insurance president from whom he would borrow a million or the national president of the union who can shut his plants down with the ease and self assurance that you or I greet an old college classmate. This is the stuff of which an executive's job is made.

Fourth, those few individuals who achieve major executive posts in large enterprises, either in Government or business, need to acquire still another set of special and complex skills. Executives at all echelons make decisions but the magnitude of the responsibility at the uppermost levels is so much greater, the stakes so much larger, that the very process by which decisions are made is different in kind. The foreman who can meet each of his workers and deal with them on a face-to-face basis has problems of communication. But the executive who must communicate his opinions, ideas, and policies to thousands of individuals scattered from one ocean front to the other has infinitely larger and more difficult communication problems.

Leadership is one thing for the manager of a small, well-knit, compact group; it is vastly different for the president of General Electric who must give direction, stimulate, and speak for the thousands who make up an industrial empire.

In short, what I want to get across to you is that some responsibilities of the executive, while similar in kind, are so different in degree from those of his subordinates as to be very different in fact. The differing character of these tasks make up what I call the "executive process."

Essential Habits

He who masters each of these four fields of knowledge will still not have become an executive. You have seen in many fields, the guy who has plenty of "book larnin" and yet is ineffective at making it work. So too it is with the potential executive. The golfer, after he has read the book, must develop the habit of keeping his head down and his left elbow stiff. The would-be executive, after learning what there is to know of these four areas, must develop five habits.

First and foremost, the would-be executive must trust other people. He must have a minimum of the NIH factor (not invented here!) in his makeup; he must be able not only to welcome the ideas of others, but to plant his own ideas in the minds of others and to compliment them on their ingenuity. His receptivity must go to the point of exercising great powers of self-restraint. He doubtless was an expert in his own field yet he must possess sufficient restraint to enable him to be content with exercising broad controls over results and to refrain from telling the sales manager how to sell, the comptroller how to keep his accounts, or the personnel man how to do his job no matter how expert he may have been in any one of these fields.

Secondly, he must no matter how experienced, learn to rely on facts. He must habitually deal with each question in turn on the basis of the facts. He can not afford to rely on experience, a much over-rated asset. There are two reasons <u>why</u>.

Coleridge has said that experience is like the stern lights on a ship; it illuminates only the past. Only by consideration of the facts, day after day, can experience be kept up-dated and continuingly worthwhile. Second, the assertion of experience, like the "pulling of rank" is a first-rate way of discouraging the young and capable assistant. Recourse to facts provides an objective basis for rejecting the assistant's proposals while contributing to his understanding; the mere assertion of experience contributes little to developing an individual for whose development the executive is responsible.

Thirdly, in my experience, the successful executive is always marked by an <u>insatiable curiosity</u>. It is this curiosity that enables the successful executive to keep his decision-making batting average up. Successful executives, as I have seen them, in business and in Government, are constantly seeking to learn about every facet of the enterprise for which they are responsible. They are not content to sit "on high" and to bless someone's recommendations. Their metabolism is such that they have to poke their noses into one corner of the business after the other and they do so with the uncanny facility of while having their noses in, they keep their fingers out.

Fourth, the successful executive intuitively senses the reactions of those whom he must persuade. These will include at one time the bankers, at another time the customers, at another time the union negotiators, and at still another time the employees. The successful executive develops the ability not only to understand those with whom he will deal, but to talk their lingo with an appreciation of what it means to them and what reactions it will engender. This is indeed a fine art and an essential one.

In passing, let me suggest that "specialists" "break their picks" most often by failing to sense the problems of, understand the reasoning of, and to speak the lingo of their bosses.

The problem is, after all, a relatively simple one. The specialist must talk to the boss in terms of the frame of reference in which the boss will evaluate the specialist's recommendation. The specialist who talks only in his own lingo, and thinks only in terms of his own frame of reference, is a tiresome assistant who helps little and will not likely grow far.

Fifth, the truly successful executive budgets his time with the parsimony (and probably much greater skill) than the newly married couple budgets their meager resources.

Most of us have limited control over our own time. Deadlines are set for us. Staff meetings are scheduled without our consent. Appointments are fixed at which we are expected. Our time is in considerable part planned (or misplanned) by others, usually our superiors.

The executive is substantially the master of his own time. That mastery, however, is not freedom, because he is besieged with demands upon that time. His success depends upon his ability to effectively utilize that time.

If he learns to schedule his time even as the miler learns to pace himself, he will accomplish much, be readily available to his staff and to those from without who would see him, and at all times exhibit an air of placidity and casualness that is the mark of any man truly in command of his own resources. If he fails to learn how to manage his time, he will be difficult for for his staff to reach, he will antagonize key customers, he will continually wear that look of executive harassment, and eventually he will die of ulcers or a coronary. Managing one's time is a habit that can be acquired and must be if one will succeed as an executive.

Summary

This is my prescription for executive development. I have broken executive development down into nine components. Each is a definable, distinguishable piece that the industrial engineer who hopes to graduate from the ranks of a great profession to that of a better paid one, if not a greater one, can master.

How, you may ask? Opportunities are at every hand in most firms today. There are developmental programs within the plant and the crown princes are sent off to universities.

But after all, most men are developed by every day's experiences.

Let me drive this home by a homely story. My son came home from camp one summer with a different and unusual walk. He carried his shoulders differently somehow; his stride was somewhat changed. It was noticeable but the reason was not clear. Then one day one of his counselors he had told us he admired greatly came by to visit him. Seeing this older boy walk up the pathway made perfectly clear where my son's altered carriage had come from. He was copying one whom he admired.

This is the way you and I have learned much of what we know today. It is the way many executives are developed. In your company and in every other company, there are successful executives who never heard of any one of the four areas of knowledge and five habits I have described, but who practice each. Watching and copying them will teach more than all the books or even the courses that one can take. This is executive development in the first person. If you accept my diagnosis of the nine components of executive capacity, then you know what to look for in the executive whose example can show you the way up the executive ladder more surely than any book or course.

My best wishes for your development as executives.

• THE EMERGING NEED FOR MANAGEMENT'S LORE

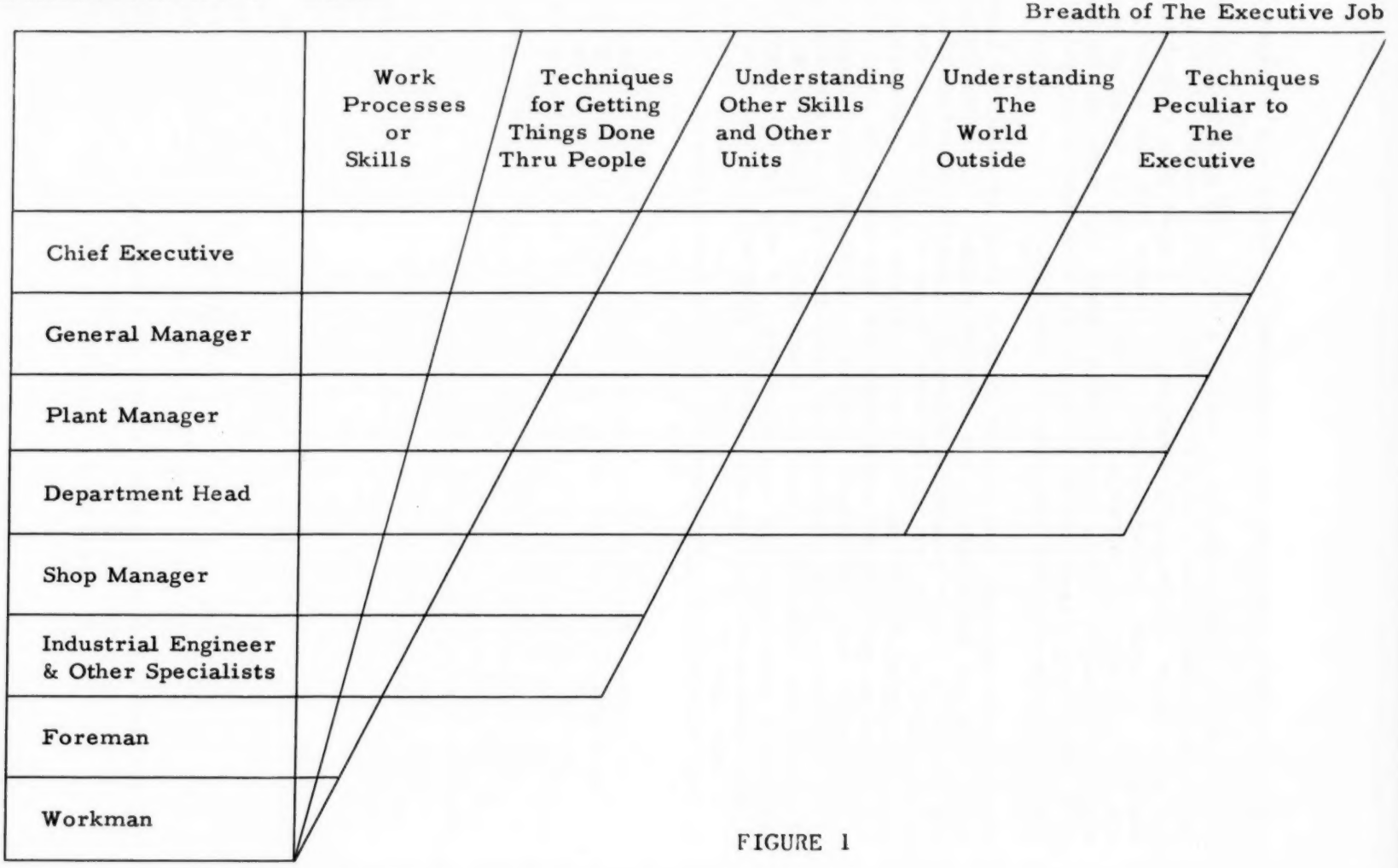

FIGURE 1

THE LORE OF MANAGEMENT

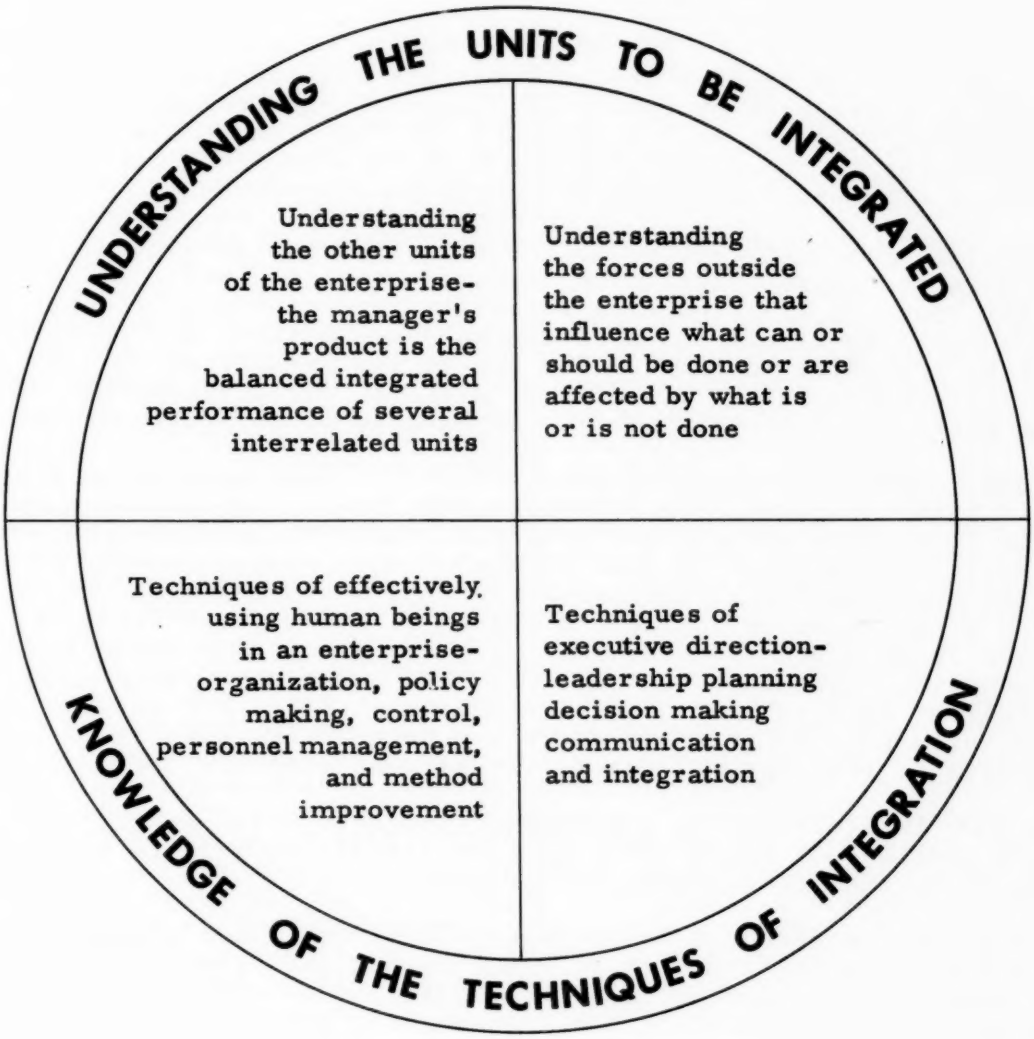
UNDERSTANDING THE UNITS TO BE INTEGRATED
Understanding the other units of the enterprise- the manager's product is the balanced integrated performance of several interrelated units
Understanding the forces outside the enterprise that influence what can or should be done or are affected by what is or is not done
Techniques of effectively using human beings in an enterprise- organization, policy making, control, personnel management, and method improvement
Techniques of executive direction- leadership planning decision making communication and integration
KNOWLEDGE OF THE TECHNIQUES OF INTEGRATION

FIGURE 2

OPERATIONS RESEARCH IN ACCOUNTING

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Perhaps it would be more accurate to call this paper, "Operations Research by Public Accounting Firms" rather than "Operations Research in Accounting." But in either case a few words of introduction might be desirable to indicate the relation of operations research to public accounting.

Operations research relates to the activities of accounting firms in two ways. First, the basic function of such a firm, as the audit of the financial activities and status of a corporation, is in itself an operation subject to study and improvement by scientific methods. The use of statistical methods to aid the auditor in certain of his tasks has already achieved some success and we will mention an example of this type later.

Second, management has long made a habit of capitalizing on the audit firm's experience and knowledge by requesting auditing firms to conduct special projects for them. While these projects normally were related in some fashion to the special knowledge of the auditing firms, the areas where this knowledge has been found to be valuable includes a number of the major activities of the corporation, such as inventory and production control, forecasting, planning, cost systems, and budgetary controls. Operations research has demonstrated its ability to contribute to problem-solving in these areas and hence is a valuable addition to the capabilities of the firm on such projects.

Thus, OR is useful in an accounting firm in doing research on the activities of the accounting firm itself, as well as in supporting the special work for clients.

In this presentation, I would like to describe three projects as illustrative of the work in which accounting firms are engaged. The first is an application of statistics to an auditing problem. The second is an application of linear programming to production scheduling. The third is the description of an attempt to develop a set of principles useful in increasing the utility of top management reports, and the results of the application of these principles in a particular case.

APPLICATION OF STATISTICS TO AN AUDITING PROBLEM*

As you all probably know, an auditor, generally speaking finds it necessary to satisfy himself in some manner as to the amount of physical inventory which the corporation he is dealing with represents that it has on hand. This is a case history of a fairly interesting situation where measuring the inventory and its value was necessary but a conventional physical count of items was impossible and it was necessary to resort to statistical sampling theory to solve the problem. The problem here was to establish with a high degree of assurance the value of a piled inventory of metal-bearing ore. The complicated portion of this verification was the determination of the proportion of metal in the ore on hand by a valid but economical statistical sampling plan.

The ore to be inspected is dumped in essentially discreet piles, a freight carload at a time. Thus the determination of metal content can be considered to involve two distinct concepts and associated sets of assumptions: (1) establishment of the proportion of metal in the ore under the assumption that the whole inventory consists of ore and (2) examination of enough of the individual piles to gain some assurance that most of the lots are in fact ore. There were 22 of the separate piles of ore in the inventory. 100% assaying of all of these piles was economically not feasible. Actually it is conventional to check the metal content of the ore by assaying cores drawn from the piles. Thus the problem was to determine how many cores should be drawn and where they should be taken.

In determining the method, or sample design, unrestricted random sampling by conceptually representing the surface area of each pile as a checkerboard of basic sampling units and selecting a sample was found to be unsatisfactory. This method was rejected because it became apparent that information was needed on the variation both among and within piles in order to obtain statistical assurance on the accuracy of the sampling estimates. Also, the second of the two concepts under which the test was being conducted required allocation of the sample among piles. Unrestricted random sampling did not permit allocation of effort between two such subsections of a population in a manner to minimize sample size.

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*This example was taken from a report prepared by Prof. Richard Cyert of Carnegie Institute of Technology and Mr. Robert Monteverde of Touche, Niven, Bailey & Smart. This report will be available soon as a chapter in a book on applications of statistics to auditing being completed now by Prof. Cyert and Mr. Robert Trueblood to be published later.

Since records were available showing for each pile the metal yield or percentage as assayed at the mill and again as assayed on the receipt data, it was possible to stratify the lots by anticipated percentage of metal into homogeneous groups for sampling purposes. This basis of stratification was discarded when analysis of samples drawn to obtain some initial information on the population showed that the variation among the groups was excessive.

The method finally decided on was a two-stage, randomly-drawn sample in which first a number of carload lots were selected, then from each lot two or more of the squares of the previously mentioned conceptual checkerboard were selected and from each of these a core was drawn. This allocated effort so as to cover a significant proportion of lots and enable measurement of variation within lots while minimizing sample size and hence the total cost of the analysis. The cost of a single core analysis, incidentally, was $25.

With the method established, statistical formulations were made available relating sample size to the variations of the data being sampled. The initial sample data gave unbiased estimates of the variations in the total population which permitted calculation of the sample size necessary to meet any desired limits of precision and reliability.*

To meet the first requirement of estimating the amount of metal in the ore with an associated precision, the estimated population variation among lots and within lots was computed. The former was sufficiently larger to eliminate any effect of the latter on sample size. However, compilation of some data on variation within lots was necessary to measure this variation, hence a sample size of two cores per pile was established as a minimum. A precision requirement of $\pm$2% about the mean with 5% reliability was established and number of lots necessary to satisfy these requirements calculated to be 10.

This same sample was used again to determine whether or not some of the 22 carload lots actually did not bear metal. If the sample of 10 turned out to show metal in each case then this implied that there remained a 15% risk of accepting the inventory of lots when three or more were defective. Though this protection is low from a purely statistical point of view, it was considered adequate for verification purposes since the testing was only one of several independent procedures including a review of the internal control used which was considered satisfactory.

*Precision here used in a statistical sense, hence meaning the range of values about a sample estimate within which the true population value is contained with a stated probability or reliability.

Thus the application of statistical methods led to a satisfactory practical solution of this somewhat novel inventory measurement problem.

AN APPLICATION OF LINEAR PROGRAMMING TO PRODUCTION SCHEDULING*

A paper manufacturing company was faced with the situation that total demand for their products continued to exceed their manufacturing capacity over an extended period of time. Orders were generally scheduled chronologically as received. The resultant backlog slowly but steadily increased until management decided that orders should be selectively accepted on the basis of relative profitability.

This project did not start out with an immediate application of linear programming. Help was requested initially to establish a means for determining relative profitability for the various products manufactured. There were approximately 2,000 distinct products and nine papermaking machines. It was first necessary to isolate the fixed costs and classify the variable costs, in dollars-per-hour of machine operation. From the available standard running times-per-ton of product this variable cost could be converted into dollars-per-ton of product and subtracted from sales price per ton to yield the relative profitability of each product. It was assumed that the total available machine hours for a schedule period then would be loaded with items in order of decreasing profitability until capacity was reached and the remaining orders rejected. At this point the problem appeared to be simply the routine task of making this cost-computation for the approximately 2,000 end products.

As the collection of detailed cost data and running times progressed, several points contributed to the difficulty of the problem. For one thing, the time (or cost) it took to make a product differed markedly among the nine papermaking machines. Many products had never been made on all the machines so no historical data were available. Fortunately, at this point it was also observed that certain of the 2,000 end products logically could be grouped into about 350 fairly homogenous subgroups.

As a result of further consideration of the first point mentioned above, it became clear that over-all profitability of the system would not necessarily be achieved if products were assigned to

*Reported by D. W. Jennings and Francis Walker of Touche, Niven, Bailey & Smart at the December 1955 national meeting of the Econometrica Society in New York.

machines solely in order of decreasing profitability. For example, it was evident that though Product A might attain its greatest profitability on Machine #1, this selection might result in forcing Product B onto Machine #2 at such a low profit that the total profit would be less than if the combinations were reversed. Such an error and how to compensate for it might be obvious in a 2 machine-2 product problem, but it is not obvious for nine machines and 350 products. Recognition of this problem, suggested the desirability of using linear programming if possible.

Using the profitability figures which had been developed, the problem was expressed mathematically in a linear programming form. The general, exact method of solution for this problem, the simplex method, was found to be inapplicable because of the size of the matrix involved (359 by 700) and because access to a computer which might have handled this problem in a reasonable time interval could not be obtained on a workable schedule or at feasible cost.

Further study of the matrix structure by Professors W. Cooper and A. Charnes then of Carnegie Institute of Technology, who were retained as consultants on the problem, resulted in the conclusion that the numerical form of this problem was such that it closely approximated that of the simpler form of linear programming problem, the transportation form. This form has the happy characteristic that even for large matrices it can be solved manually in a reasonable time by relatively simple numerical techniques.

The condition not presently fulfilled by the problem and which had to be met to transform it into the transportation form required essentially that for each product-machine combination the conditions of the problem be modified in such a way that the ratio of tons to hours be one. In rough terms, this step is essential in order that one ton of each product (or its adjusted equivalent) correspond to one hour of machine time so that the units of the products be interchangeable. It was apparent that although the characteristics of the initial formulation made it possible to make some adjustment, which would bring this about approximately; it was by no means possible to conclude that this was a general procedure.* Without going into the technical reasons behind this move, suffice it to say that it is this increased flexibility which

*Various checks of the significance of this approximation indicate surprising lack of sensitivity of the final answer to the approximation. No general theory for estimating the exact answer is known to be available at the moment, however.

permits more rapid numerical solution of the transportation model. It should be noted that after solving the problem in the transportation form, the answer must be readjusted back to fit the original real situation.

To help you see how all this works, a simplified problem of this type is shown in the first slide. Products are shown on the lines with maximum requirements noted at the left; machines are in rows with maximum capacity noted at the bottom. The figure in the larger section of each square is hours-per-ton and in the smaller section is dollars-per-ton. Specifically the problem is to convert the figures in the large section of the boxes to ones using only the following two types of moves which we can illustrate in the next slide. First select adjusting factors for the columns in the manner shown in the slide and then select adjusting factors for the rows as also shown. The use of adjusting factors in columns affects machine capacity and the row factors affect profitability and product requirement, which in turn then must be adjusted accordingly. Once the problem is set up in this form, the rim conditions must then be satisfied in the usual way and the stepping stone method (or other method) can be used to solve the problem.

This system was installed for loading machines on a weekly schedule. The problem is solved by essentially an untrained man in about 2 hours. This method was run experimentally alongside the existing judgmental loading and yielded results 20% better than the judgmental loading.

In addition to improved scheduling this study disclosed the inadequacy of existing cost data and led to a significantly improved cost system. Thus, although strictly speaking, there are many ways in which this application might be improved theoretically, on a purely pragmatic basis, the installation was considered a success in that it afforded significant improvement at slight cost.

MANAGEMENT REPORTS

Turning now to our third case, management reports; the necessity of improving such reports, particularly the top financial reports, has been receiving more attention in recent years. There has been an attempt to develop certain specific tests for the review of such reports. These tests might be summarized in tentative and informative fashion as follows:

(1) Does the information relate to the particular responsibilities of the person who will read it?

(2) Are the data limited to those kinds which conceivably would be useful in carrying out such responsibilities?

(3) Are insignificant digits included?

(4) Are the data appropriately classified and summarized?

(5) Is the figure information shown in relative terms wherever practicable, i.e., per cent or per unit?

(6) Does the report form highlight the exceptions which require management attention?

(7) Is the report form designed for easy readability with attention to symmetry and avoidance of over-crowding?

(8) Has the rule been observed that the more figures in a given space the less information the reader is apt to receive?

(9) Has the distinction been recognized between information to be routinely reported and that which is useful only temporarily and intermittently?

(10) Has the necessity of timeliness been observed?

While these "tests" are far from completely adequate from a scientific point of view, nevertheless their repeated application by different individuals had led to surprisingly similar and useful results. The kind of results achieved can be illustrated by the following two slides which because of the confidential nature of the information contained therein have been modified numerically from the actual reports from which they were taken.

The first slide is an example of a conventional, popular form of a report to top management of operating statistics for a manufacturing company, here called the XYZ Company. While this report is considerably better than some that might be shown, let us see what happened when the simple tests mentioned above were applied.

The next slide shows this same report modified in accordance with these tests. Without going into great detail, it is immediately evident that many unnecessary numbers have been dropped from the first report, that the categories of information shown have been reduced, and that new information in the form of month to month repetition of certain quantities has been introduced for comparison purposes.

To purely scientific personnel this change may appear somewhat less than earthshaking. Others more familiar with this field will recognize that these reports break with at least one time-honored and carefully preserved tradition, the requirement

that totals be presented accurate to the cent and that any breakdown of these totals be given completely and with the same accuracy so that totals may be verified.

Reports like these to top management and reports at all levels of management have been changed as a result of a "new look" and are now being successfully used in industry. While this in itself is important, perhaps the greatest contribution of the development of these useful tests is that it helps to make practicable the application of quantitative scientific methods to this field.

For example, we have the application of mathematical techniques (statistical quality control) to the evaluation of the performance of units of a particular manufacturing operation, the development of a useful graphic form of presentation of this information to management, and the establishment of consistent quantitative performance criteria. Accountants have long been active in such related fields as budgeting, forecasting, and cost systems; some are currently in the process of conducting long-range research studies in the general field of management controls of which, of course, these reports play a big role. Through the further application of scientific research directly on design of management reports, it is hoped that a beginning will be made toward pulling these widely diversified areas together into a common focus.

CONCLUSION

It has only been possible to give you a brief summary of these three cases. Very likely I have raised considerably more questions than I have answered. However, I hope I have been able to contribute to some extent to your further understanding of the nature of operations research, how it works, and the diversity of areas in which it can be applied.

INITIAL DATA

CHART I

MAXIMUM TONNAGE	MACHINE / PRODUCT (M / P)	1	2	3	4	5
11,500	A			10.20 / .424	9.10 / .473	
126,200	B	7.90 / .246	6.50 / .501	7.60 / .471	7.10 / .511	8.10 / .534
10,800	C	5.40 / .183		6.40 / .376		
5,700	D	6.40 / .238				6.30 / .448
3,400	E			8.60 / .436		
11,700	F	11.60 / .245	7.50 / .469	8.90 / .415	11.90 / .480	
2,800	G		2.90 / .456			4.60 / 42.7
1,100	H	4.00 / 2.48				
950	I					4.20 / .496
150	J					3.80 / .440
CAPACITY IN HOURS		6864	6864	6864	6864	6864

ADJUSTMENT OF PROFIT RATE

AND MAXIMUM TONNAGE

CHART 2

PRODUCT ADJUSTMENT FACTOR	ADJUSTED MAXIMUM TONNAGE	MACHINE / PRODUCT	1	2	3	4	5
.916	10,500 ~~11,500~~	A			~~1120~~ 1020 902 ~~424~~	~~990~~ 910 825 ~~473~~	
1	126,200 ~~126,200~~	B	~~730~~ 790 1.00 ~~846~~	~~650~~ 650 1.00 ~~801~~	~~760~~ 760 1.00 ~~471~~	~~710~~ 710 1.00 ~~511~~	~~610~~ 610 1.00 ~~534~~
.766	8,300 ~~10,800~~	C	~~710~~ 640 743 ~~183~~		~~840~~ 640 798 ~~376~~		
.90	5,100 ~~5,700~~	D	~~730~~ 640 959 ~~238~~				7.00 ~~630~~ ~~889~~ ~~448~~
.924	3,100 ~~3,400~~	E			~~930~~ 860 924 ~~436~~		
.918	10,800 ~~11,700~~	F	~~1260~~ 1160 995 ~~248~~	~~820~~ 750 934 ~~469~~	~~970~~ 890 881 ~~415~~	~~1300~~ 1190 940 ~~480~~	
.858	2400 ~~2,800~~	G		~~340~~ 290 908 ~~456~~			~~540~~ 460 798 ~~427~~
1.02	1,100 ~~1,100~~	H	~~390~~ 460 102 ~~248~~				
.930	900 ~~950~~	I					~~450~~ 420 930 ~~456~~
.825	100 ~~150~~	J					~~460~~ 360 825 ~~448~~
ADJUSTED CAPACITY IN HOURS			~~6864~~ 27,800	~~6864~~ 13,700	~~6864~~ 14,500	~~6864~~ 13,400	~~6864~~ 12,900
MACHINE DIVISION FACTOR			.246	.501	.424	.473	.534

"MEMOMOTION - A PRACTICAL INDUSTRIAL ENGINEERING ANALYSIS TECHNIQUE"

Samuel W. Earle
Union Carbide and Carbon Corporation, New York, New York

Ladies and Gentlemen, it is a pleasure to be here this morning and to be able to discuss with you some of Union Carbide's work with the memomotion technique. I think we all realize that a mutual exchange of information on Industrial Engineering techniques can be advantageous to everyone.

This morning, I would like to preface my memomotion remarks with an outline of the Corporation's Management Services Department and what we consider to be the areas of Industrial Engineering. I will present a general discussion of the application of the memomotion technique in many of the areas. Next will be a detailed discussion on two projects, illustrated with slides and films, including the study, and analysis and presentation of data. Finally, I will comment on and show you the equipment required for such a study. We have material to pass out for those who desire additional information concerning the equipment sources, and further background in this technique. (This material is not included in the proceedings, but can be obtained by writing Management Services Department, Union Carbide and Carbon Corporation, 30 East 42nd Street, New York 17, N.Y.)

UNION CARBIDE AND CARBON CORPORATION

A quick word about Union Carbide might better acquaint you with the Corporation's activities and will assist you in understanding the role of the Management Services Department.

Union Carbide and Carbon Corporation was organized in 1917, bringing together several companies with similar research and production interests. The history of some of these companies dates from the 1870's.

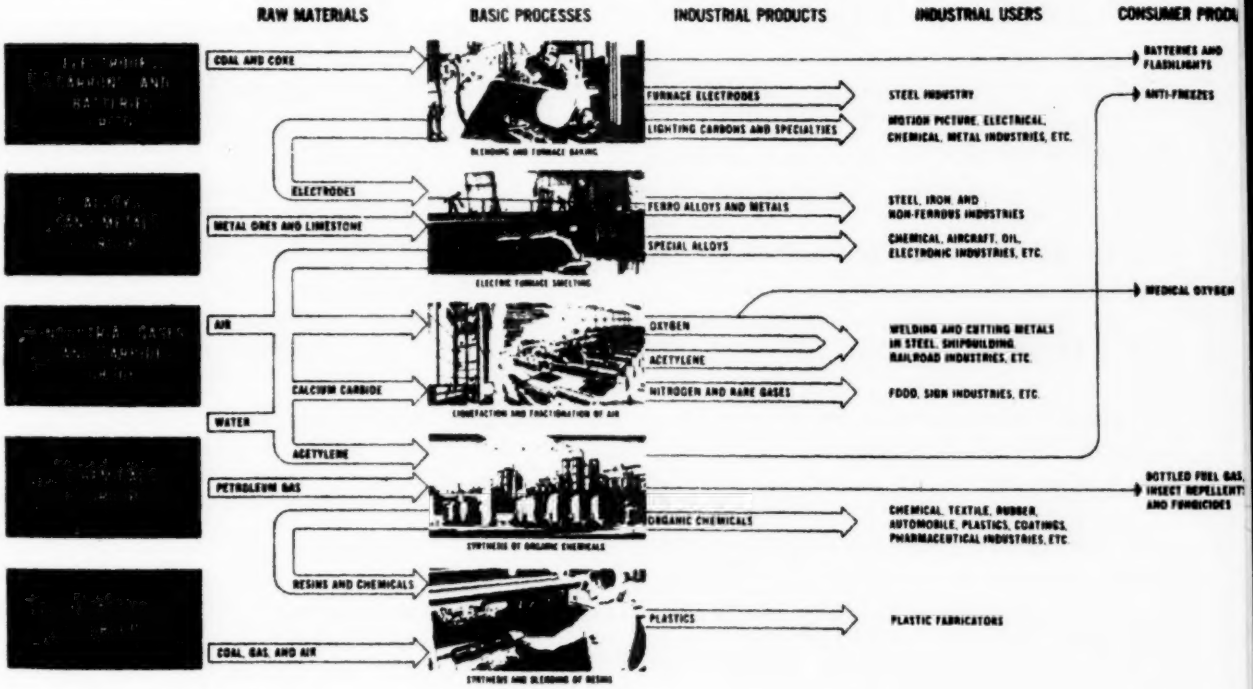
Today, UCC is one of the nation's large and highly diversified manufacturing corporations. Its operations extend into six fields; ferro-alloys and metals, carbon products, gases and organosilicon products, chemicals, plastics and nuclear energy.

Few companies are concerned with so many complex and technical operations as Union Carbide. In the plants are used processes that range between the physical extremes of heat and cold and terrific pressures and high vacuums. There are at the moment, 14 different domestic companies and divisions operating in the United States, including the international company. In addition, several divisions of Union Carbide Canada, Limited operate in Canada. We have over 70,000 employees and almost 115,000 stock holders. The Canadian and domestic facilities include over 400 plants, factories, mines, mills, laboratories and sales offices.

The Corporation's products for the most part are unseen in our everyday life, because they are the raw materials of industry. However, hardly an item is made today that is not in some way related to products and processes of UCC.

Slide 1, illustrates the major raw materials, basic processes, industrial products and uses and consumer products of Union Carbide, and shows how the various groups of the Corporation are interrelated.

The list of specific products is quite lengthy, hence this chart shows the way in which the Corporation products are used rather than specific things made by UCC.



Through research, Union Carbide is constantly striving to satisfy the five basic human needs; food, clothing, shelter, health, and transportation, by developing better and new products in our six major fields.

We have copies of the booklet, "Products and Processes", available for anyone interested in more detail.

MANAGEMENT SERVICES DEPARTMENT

The Management Services Department is a corporate management consulting department, whose function is to assist in minimizing cost and optimizing clerical and production methods.

Located in New York City, this department is under Mr. J. K. Baker, and reports to the Corporation Treasurer. Assistance from the department can be obtained by request from any of the corporate and divisional departments, which have their choice of our services or those of outside agencies. We provide technical assistance, consultation service, and training. Some jobs are completely handled by our staff; others are done on a teamwork basis, utilizing plant personnel; and some are taken on a consulting basis.

(Slide 2) There are four sections of the department: Electronic Data Processing, Procedures and Methods, Operations Research, and Industrial Engineering.

The Electronic Data Processing Section investigates and evaluates electronic computers, investigates and evaluates applications, and programs applications.

The Procedures and Methods Section is concerned with the survey, design, and installation of administrative and clerical procedures; survey, design, and installation of IBM systems; organizational review and planning; mechanizing office operations; establishing filing techniques; and coordination of Corporate procedures.

Operations Research, as we see it, is the application of scientific methods to various types of problems. This section utilizes many of the advanced mathematical tools.

The Industrial Engineering Section provides survey, design, consultation, training and installation assistance in the fields of plant and office layouts, material handling, warehousing, factory methods, factory work measurements, factory systems, and reproduction. Recently, we have become involved in establishing divisional Industrial Engineering functions. This includes training and auditing. I might add that when we establish a plant Industrial Engineering group, we also equip them to be able to do systems and procedures work, cost estimating, and methods training.

The corporate General Tabulating Department, also reporting to Mr. Baker, performs the function of a tabulating and computer service center. This equipment is used by many groups, including the four sections of our Department to solve varied problems.

INDUSTRIAL ENGINEERING

We feel that a program to be successful, must have a good foundation. In order to provide a good foundation and a uniform understanding of the Industrial Engineering function, we have adopted the following definition (slide 3):

"Industrial Engineering is that branch of engineering wherein special knowledge of the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design acquired by professional education and/or practical experience are used to solve, in a scientific manner, the problems of designing, predicting the performance of, and controlling an integrated human group activity, the related physical facilities, and accompanying pattern of interrelationship".

You will note this definition, proposed by the SAM committee on professional industrial engineering standards, (M. E. Mundel, Chairman) parallels very closely the AIE definition of the Long Range Planning Committee (Industrial Engineering Seminar, Cornell University, October 20-21, 1955). This to me is very heartening. We now have two professional societies concerned with industrial engineering, writing definitions which are identical in intent and very similar in wording.

In passing, I might add that we feel the activity of industrial engineering can be thought of as consisting of two phases: (slide 4)

Design -	Preparing plans for work to be executed.
Administration -	The actual performance or control of the design after necessary management decisions are made.

(Slide 5) Rather than attempt to circumscribe in detail the scope of Industrial Engineering, I will simply say briefly that we feel it is concerned with the five broad areas of methods, time, control, personnel, and surveys.

The individual plant size, product, objective, organization, and production volume determine the breadth of an Industrial Engineering program. One department performs the functions of office and plant layout, normal cost determination, methods, standards, jig and fixture design, materials handling, packaging, supervisory methods training, systems and procedures, and forms control.

movements in an operation to improve methods, define problem areas, or set standards. It can be considered a special form of micromotion study in which the motion pictures are taken at unusually slow speeds. (The memo card also has this definition)

It uses filming speeds of 50, 60 or 100 frames per minute, with an accurate time interval between pictures to provide a record for frame by frame analysis.

It is another means of performing the third step, Breakdown, in our 8 step systematic approach to a problem.

Micromotion, you know, is used to study an operation by its detailed motions; whereas memomotion is used to study an operation by its main movements. This distinction between detailed motions, such as therbligs, and main movements is the major distinction between micromotion and memomotion study.

Now, a word about camera speeds and the differentiation between regular speed, time-lapse, and memomotion.

As Dr. Mundel states, "Normal speed motion pictures (eight to twenty-four frames per seconds), are usually used where a record is desired which will permit a reasonably identical visual reproduction of an event. Such speeds likewise permit an examination of the fine details of the action recorded.

"True time-lapse photography in which the pictures are taken at one frame per fifteen seconds, or at greater intervals, resembles work sampling in that only a sample of a series of events is recorded. In such cases, it is assumed that either the sample is representative of the whole, or that actions in the intervals between the pictures may be inferred from the picture.

"Memomotion with filming speeds of 50, 60, or 100 frames per minute, with an accurate frame to frame time interval does not permit a true reproduction of a series of events nor is it a sample of the events, but it is something in between. The pictures are sufficiently close together in time so that all actions are usually recorded, but far enough apart so that the motion-time relationship is distorted when the film is projected in the normal fashion, even at very slow speed."

This distortion, we shall see, of the time-motion relationship when projected is actually an advantage because it emphasizes various aspects of the activity and permits rapid review of lengthy events.

WHY THE TECHNIQUE IS EMPLOYED (Advantages)

Memomotion study is used for the following reasons (slide 6): (or memo-card)

1. It provides a more accurate record than visual means for analysis and film appraisal.

2. It will record inter-related events more accurately than visual techniques.

3. It is a vehicle for work measurement, since the camera runs at constant speed.

4. It facilitates the focusing of attention on the major movements of the job.

5. It reduces the film to be analyzed without reducing the period covered.

6. It reduces film costs to about six percent (6%) of costs with normal speed.

Advantages 1, 2, and 3, above, are common to other types of film analysis, but advantages 4, 5, and 6 are peculiar to memomotion photography. (Refer also to the memo-card)

Professor Richardson states, "When the advantages of filming are desired, but detail is not necessary, memomotion study provides, by a simple frame count, an accurately timed, positive record of all the variables present in the operation. Also, the film provides a simultaneous record of many of the physical characteristics of the job which are difficult to record any other way. After data has been gathered and analyzed into meaningful categories of activity, elements can be selected or discarded. Such selection is not possible by conventional means - clock or stop watch elements once selected and timed cannot be further subdivided."

Explaining item 4 - Tony Tseng states, "By focusing attention on the major job content, since an hour's operation can be shown in about four minutes at normal projection speed (action is extremely accelerated), any non-productive movement, such as excessive walking or long delays, will be brought out more prominently than in a motion picture filmed at normal speed."

Discussing item 5 briefly -

The development of this technique was motivated by the need of economy in film analysis, not only in film cost but in analysis time. By recording action at one frame per second rather than 16 per second, only one-sixteenth of the film footage is required. Analysis and data gathering time on one job ran in the neighborhood of 38 hours using the memomotion technique. A conventional method would have consumed an estimated 170 hours.

Each of the areas of application of a study must have an objective. The purpose of making a memomotion study may be: (Vu-graph - write on or slide 8).

a. to record and improve a method

b. to define a problem area

c. to set standards

AREAS THAT LEND THEMSELVES TO THIS TECHNIQUE

The application of memomotion study seems almost unlimited. It is most useful as an aid in studying any or any combination of the following (slide 9):

a. Long cycle operation

b. Irregular cycle operation

c. Crew activities (multi-man)

d. Long period studies

e. Multi-machine operation

f. Plant layout

g. Ratio delay studies

h. Irregular occurrence in a normal cycle

i. Recorded picture histories

The key word is "aid". The film only records the events and still must be analyzed.

Because of its newness, the fields of application of memomotion are limited only by the thoroughness of the engineering data required and the operating budget.

Memomotion has been used successfully to record pictorially the detailed operation of jobs being studied, so that management and/or a union could be shown the developed methods changes. Also the technique has been used to show operational differences of two or more operators on the same job.

Application in the area of plant layout has been successful in every case. Long-cycle work showing man, machine, and material movements have usually been improved through analysis and subsequent operational changes.

Ratio delay studies, using a camera as the recording device, have been successfully made. In these studies electric clocks were used to start and stop at random the motor driven camera. With this technique, several hundred observations can be recorded on film without an observer present in the shop. We feel it is better, however, to work sample a film taken at one of the memomotion speeds, thereby avoiding the assumption that the recorded events are representative of the whole. This has been successfully done by several people.

Experiments are being made on some operations which are considered normal, but have an irregular element occurring in an unpredictable manner; for example, breaks in a process machine. By using microswitches to activate the camera when the irregular element occurs, an exact recordcan be obtained and analyzed at a future date.

PROCEDURE FOR MAKING A STUDY

Before discussing the procedure and showing you various examples of memomotion study, I would like to call your attention to two features.

First, we consider the camera another member of the Industrial Engineering Department. We utilize the camera to do a job where the camera is an obvious tool to gain the desired result. It is considered a working tool, not a luxury gadget. Second, we use fast film and no auxiliary lighting since the primary purpose is to record data. Consequently, the pictures were taken with a minimum of fuss and as economically as possible. Weusually get good pictures, but we do not aim for anything extra special. Many of the pictures you will see, were made by people with only "Brownie" experience. After a half-hour instruction, anyone can take these industrial movies.

Let's start by showing the difference between action recorded at regular speed and memomotion speed. First let's look at a short strip of regular speed film (1000 frames per minute) taken by Messrs. Wright and Thompson of our Texas plant, showing an automobile starting, driving a given distance, stopping, discharging and picking up people, turning around and returning to the starting point. (f i l m) (66 seconds)

Now let's look at the exact same condition taken at memomotion speed (60 frames per second in this case). (f i l m) (5 seconds)

You have seen 66 seconds of activity -- the latter, when projected, highly accelerates the movement. Your memo card shows, as does (slide 8), the procedure for making a memomotion study.

The procedure is generally divided into four major steps:

1. Planning for Filming

    a. Inform shop personnel

    b. Plan Camera setup

    c. Arrange to gather supplementary data

    d. Determine memomotion speed, period to cover, estimated total filming needs.

    e. Check your equipment

2. Filming and Data Collection

3. Analysis of Operations

4. Presentation of Results (usually graphic presentation for study, criticism and improvement) and formulation of improvements.

Let me explain briefly, the general content in each step.

Step 1 is Planning For Filming

Talk the project over with your shop people and be sure also that industrial relations knows the purpose and technique of memomotion study. Sometimes to differentiate between crew members, we ask them to wear different clothes or numbered jersey slip-overs.

Survey the job area a day or so in advance, and check the camera angle, electrical outlets and the route of a mobile study. Check the lighting to ascertain the type film, lens, and filters requred. We do not use supplementary lights. Arrange to gather supplementary data such as pace rating films, secondary adjustment information, records and reports, plans and layouts.

Based on one of the three memomotion speeds, the cycle time, and objective of the study, determine the time interval to be covered. By conversion determine the film footage required. Take a roll or two more to the job than you need for the job.

The day before, check the operation of your motor drive and camera equipment and be sure you have enough film. Check the auxiliary equipment such as extension cord and proper plugs, tripod, dolly, and exposure meter. Also check lens, filters, title board, chalk or crayon, wrist watch or clock, and note paper. A portable wire or tape recorder often facilitates note taking.

Secure an explosion meter when required.

Step 2 is Filming and Data Collection

Record on a Film Study Data Sheet (slide 13) the detail of the filming operation. This sheet is keyed into the film. It is very complete and includes a work place and camera set-up sketch. This sheet also aids in determining why film results may be faulty.

Prior to filming at memomotion speed, a few feet is run off at regular speed. At this time we usually place a title board in front of the lens showing plant, location, department, operation, date, time, and filmed by. This same data is lettered on the box to identify the film further.

Step 3 is Analysis

Depending on the jobs studied and the objective, the analysis can physically be recorded on paper in any one of a number of ways.

In general, however, the film is usually reviewed at a slow projection speed, say 8 frames per second, to redetermine the problems and the degree of analysis. Any non-productive movement becomes quite evident during this period. You look for work assignments of individuals and their interrelationships. Then you determine and define categories of work. Another quick look at the film to reaffirm these categories, and you are ready for detailed analysis.

The film is examined frame by frame, recording the time for each category The categories are totaled and presented in some graphic manner.

Sometimes the data is tested statistically to record and indicate its reliability.

Oftentimes a rating factor is applied, but not always. Mr. Clarence Allen has an excellent paper on the objective rating system. We also use this system. It is composed of a multi-image film for pace comparison, supplemented by tabulated secondary adjustment for job difficulty.

Step 4 is Presentation of Results

The manner of execution of this step also varies, depending on the study objective. We try to present a simple, graphic picture that can easily be explained as portraying the activity studied.

EXAMPLES

Let's run through two examples. We have literally hundreds of rolls of this type of film, and it is difficult to know what to present. We have chosen examples showing a multi-man and machine and a man and multi-machine. If any of you wish other examples, please write me and I'll put you in touch with others who have films showing other applications of this technique.

Turn on the projector please, so we can see a still picture of the work area of (example 1). We are about 150 feet from the machine. We have about a 200 foot camera angle. We need no lighting between 7:00 A.M. and 11:00 P.M. We have a multi-man and machine problem here; 9 men and one machine. We were asked to determine if the output could be improved. The stated purpose of the study was to analyze the rolling operation to determine the percentage of time spent on each phase of the operation. It was felt that the study of the job would lead to improved methods, the exact nature of which was not preconceived.

We had limited Industrial Engineering personnel. If we took a conventional motion study and analyzed the work with a stop watch or clock, we would take 10 studies and obviously the last study would have no relationship to the first. It was decided to run a memomotion study over a 16 hour period.

We determined the camera angles, etc., set the camera up and ran it continusously for 16 hours, changing film every hour. This gave us 16 rolls of memo film plus some pace film.

The film was then reviewed to determine the degree to which the problem should be analyzed. We ran through the film quickly at 8 frames per second. Let's see about 100 feet now. (f i lm)

(That was one hour of activity)

The preliminary analysis showed that a greater portion of savings could be realized by analyzing the relation of the crew in total to the mill, rather than the individual relationship of the nine-man crew to each other and the mill.

Since I plan to demonstrate the analysis technique on the next example, let me just summarize our findings from example 1.

The analysis showed that of the 86% of available rolling time, 35% was waiting for material to heat to rolling temperature. It was estimated that the employee's efficiency could have been increased by approximately 5 to 10% through job standardization. In other words, without having to go through the tedious task of studying each man and a machine for 16 hours, we were able to determine where a 35% increase in production was possible. The management proceeded to correct the waiting period. One of the corrective actions was to reduce the size of load and increase the frequency of load returning to the preheat furnace.

Let me point out the advantages of this type of study. If we were to analyze each man, we would only need to run through the film 9 times plus one for the machine. However, our preliminary review indicated this would be wasting our time, and we should go after the dollar savings not pennies.

The memomotion study took 16 hours. A stop watch study would have taken 160 hours. The memomotion analysis took 40 hours. We estimated a conventional study analysis would consume 160 hours. We have a total of 56 hours vs. 320. This is the equivalent to adding between two and three men. The Industrial Engineering manpower saving paid for the equipment.

Another example of reduction in analysis time was the original study for fork truck standard performance time by John Cross at Purdue under Professor Richardson. The complete analysis took only 100 man hours vs. 1200 if done conventionally.

Our presentation included a sketch of the work area, a flow diagram, and group activity sheet. The film was also shown to the persons concerned.

(Example 2) - Another job you might be interested in involved a man and multi-machine problem.

The purpose of the study was to analyze this man's task, determine the percentage of time for various work categories, and determine manpower requirements. It was felt that the study would lead to the development of methods improvements.

We chose the memomotion technique because:

- of a long cycle operation (every two hours)
- the job had irregular occurrences at indeterminate times in a normal cycle
- we wanted a recorded picture history, thus enabling method improvement suggestions from everyone concerned with the activity (hourly, technical, supervision, and management)

Again a 16 hour study was made with check or pace film taken once an hour. The film was reviewed to establish the categories of work and the degree of analysis. Twelve categories were established and the film analyzed.

Let's look at the job (still picture from projector). The task is performed over an area of 140' x 100' on two levels. This necessitated following the operator with the camera mounted on wheels. The major portion of the job involves reading, recording devices, performing periodic process checks, adjusting equipment to maintain quality and quantity requirements, and maintaining good housekeeping and safety.

Let's run through part of the film. Stop here and back it up. That's enough.

I will now run through a few frames to illustrate how an analysis is made. I'll write the values here on the Vu-graph. I'll set the counter at O starting with the category of "Read and Record". This is the end of that activity and the counter now reads 325. The man now rests. This action stops and now the counter reads 600. By successive subtraction, the elemental time data can be secured. The data is added up and converted to a percentage of the total. In this case we did not rate.

We presented the results graphically (slide 13) as part of a report.

Equipment has been relocated, and various additional pieces of equipment purchased, resulting in the elimination of unnecessary walking (about 60 minutes of walking eliminated). We reduced movements from the higher classification of 5th and 4th degrees to those of 3rd, 2nd, and 1st degrees and eye movements. This resulted in a 28% reduction in the man's scheduled time for the task. The investment for improvement was realized in less than eight months.

In our opinion, the simplification of the job through improvements resulted from many people's efforts. One of the biggest plus values of the film in this case, is that everyone concerned would see the operation and make suggestions for improvement. The review of the 16 hours of activity took 2 hours, which included time of film stoppage for discussion purposes.

Recapping the time for this study:

Filming	16 hours	
Analysis	30 hours	(11 categories plus walking. The film was run through four times.)
Presentation	4 hours	(includes graph and personnel review)

EQUIPMENT

We have displayed on the stage, the equipment necessary to make a memomotion study.

They include:

Camera with lens and filters

motor drive

projector

tripod

exposure meter

screen

splicer and rewinder

extra cords

proper outlet plugs

dolly

suitable carrying equipment

title boards

chalk or crayon

clock

note paper

film

We have discussed today, a technique whose application is limited only by the personnel using it. Again, let me say that memomotion study is a proven industrial engineering tool for analysis. Through its use, factual data can be effectively and economically recorded and collected for analysis

to assist in accomplishing a desired purpose - develop more economical methods, define a problem, or develop more effective measurements of performance.

It has been a pleasure to be able to discuss some of our work with you today.

Thank you.

AUTOMEASUREMENT

Gordon R. Ewing
Industrial Engineer
R. R. Donnelley & Sons Company
Chicago, Illinois

Today I would like to discuss how Industrial Engineers are going to improve their techniques to cope with productivity problems in automated factories. I am particularly concerned with an area of work measurement which we have all recognized as troublesome; namely, the application of conventional time study techniques to other than short cycle, highly repetitive operations. There are indications that the age of automation, which is already upon us, is going to aggravate our problem significantly.

Fifty-three years ago next month, F. W. Taylor first presented his classic paper on the study of a pig iron loading operation. You will remember this experiment involved picking up the pigs, carrying them fifty feet and loading them into a box car. This was an early application of time study. Taylor chose an operation that had high volume, on which methods could be standardized, and on which a performance rating could be set. This was an example of what we will call a "short cycle, repetitive operation".

But "short cycle, repetitive operations" do not account for all of the work that we Industrial Engineers are required to measure. Other operations, which generally require a higher level of mental activity, can be classified as "long cycle, non-repetitive operations". For example, in the printing industry, the set-up or makeready of a press may require from 1 to 30 hours. Here, a skilled craftsman has control over the sequence of elements to be performed and perhaps also the method of performing these elements. This type of operation is usually concerned with a much greater number of variables, many of which are not readily predictable.

You can find examples of both the "short cycle" and "long cycle" types of operations in every company. Usually, however, one type or the other will predominate in a particular industry. It is in the "short cycle" type operations that the original time study techniques with subsequent refinements have been applied very effectively. The largest proportion of the efforts to apply and develop time study techniques has been directed toward short cycle operations. Applications of these same techniques have been made on long cycle highly skilled operations, but due to the high degree of complexity of these operations, the results have left much to be desired. Work measurement application to "long cycle" operations is a "weak link" in our present industrial engineering programs.

With the age of automation upon us, we find that many of the short cycle operations are being absorbed into integrated systems of machines. The principles of automation provide that job functions which are basically cyclical and which require a low order of reasoning and low order of memory can be performed by automated devices of one type or another. Among the tasks which can be so performed are the automatic positioning of materials in and out of machine tools by power transfer units, automated devices with small memory systems which will program the cycles of a multi-cycled operation, or instruments with the capabilities of feed-back mechanisms such that adjustments can be fed back thus eliminating the necessity of manual adjustment.

All this further indicates that the proportion of short cycle operations will tend to decrease as engineering moves toward a concept of production in the automated phase. It should be noted that in "long cycle" operations the required skills come in non-repetitive patterns. It is impractical in these operations to stand with stopwatch and board in hand and record fixed time as we would for repetitive short cycles. Automation is bringing job enlargement through technology and it is this vision into the future which sets up the warning signal to the alert Industrial Engineer. A glance at his current work measurement tools shows him that he is with present techniques inadequately prepared to cope with these changes in production methodology.

In simple language, automation will increase the proportion of "long cycle"operations in industry. Therefore, our problem is, how shall we as Industrial Engineers cope with this increasing proportion of long cycle operations when we recognize that it is the weak spot of work measurement?

Before we consider possible answers to our problem, let us review the obstacles which have stood in our way:

(1) The "long cycle" operations include very many variables, some of which are not readily predictable.

(2) If we agree that no standards should be set without adequate sampling, we face the situation where both the observation and the computing time would be increased beyond the point of reasonable cost return. In many cases, the observation time would be multiplied many fold in order to obtain an adequate sample in the non-repetitive work cycles of the automated age. For example, sixty cycles of a one-minute repetitive operation can be studied in one hour. The data can be analyzed in one more hour, and an accurate standard can be prepared in less than half of a day. The set-up on a modern printing press, however, involves the work cycle of perhaps ten hours of a highly skilled crew of four or five people. Here sixty cycles would require 600 hours of time study, and careful observation

of each of the members of the crew would increase this by a factor of four or five. This would bring the time study problem up to 2400 or 3000 hours of observation time alone merely to get a standard on press set-up that is as accurate as the standard on the one-minute work station.

The computational time would go up at least in geometric proportion to the increase in observation time. These factors should not only frighten the average time study observer, but make it impractical for management to spend the kind of money necessary to insure wholly reliable standards.

You may say that Industrial Engineers have been setting standards successfully on these kinds of operations for years. Careful analysis of situations of this type will show that in nearly every case the work measurement procedures result in rather wide tolerances associated with the standard. Doubt about the accuracy and a desire to be fair to the worker causes the standard to be established on the loose end of the tolerance range. Such a standard is almost always better than no standard for production management, and for this reason these practices have been accepted to date. Standards which are consistently on the loose side are not going to be acceptable when more accuracte standards can be developed by the application of the principle of automeasurement and statistical analysis.

(3) In order to obtain reliable standards with our present work measurement methods, the Industrial Engineer would have to spend his time on these endless data collection and processing activities. This fails to properly utilize available talent and has an adverse effect on the engineer's morale. Under these circumstances we cannot hope to recruit and maintain an adequate staff in the face of the present shortage of engineers and well trained technicians.

How can we overcome the obstacles to effective applications of work measurement on "long cycle non-repetitive operations"?

Today the Industrial Engineer is the man on the management staff responsible for conducting the studies to optimize the factors of production. To do so he has used the tools now in his possession; namely, time study including rating, methods of standardization, right and left hand charts, and so forth. In the future, faced with a different set of production factors, he will have the choice of either developing new tools to cope with new kinds of production methods or he will leave the field open to other engineering and scientific groups who will develop the techniques to optmize production in the new type of manufacturing set-up. Evidence of this is already seen in the work of

the Operations Research group and in the work of the Institute of Management Sciences and others. Bluntly, the Industrial Engineer can either let these groups cut the ground out from under him, or improve his techniques to meet the challenge.

Certainly we can't spend our careers and our employers' dollars with a stopwatch in hand when the returns of such time may be non-profitable. Instead, our solution lies in harnessing the very thing which is accelerating the change. Time study itself must be automated.

Manufacturing methods have changed drastically since the birth of time study. Pig iron loading today can be performed with fork truck and palletized loads, or by a conveyorized materials handling system. Thus the job on which Taylor conducted his original studies has been outmoded and replaced by new methods. Perhaps endless time study data collection and processing activities by manual methods are now becoming obsolete. Developments that may be applied to our field have far surpassed the usage that the Industrial Engineer has put to them. The fields of quality control, opinion sampling, and economic forecasting point out what we can achieve with these tools. We must make our data collecting and processing conform to the statistical sciences.

At Donnelley's we have coined the term automeasurement, and we define it as the system and techniques involved in the automatic collection and processing of data for purposes of measuring productivity in a statistically scientific manner. We believe that a science of automeasurement must be developed to handle the productivity studies arising in integrated systems of machines, processes, and crews for automated or mechanized production. The principal tools of automeasurement are automatic data collecting devices, computers to process the data, and the mathematical principles of statistics.

I don't believe that the instrumentations for the measurement need be limited to a stopwatch or a gauge to measure time. Our instrumentation program for measurement must include more than just gauges to measure volume output and time. We must include measurements of all production variables which significantly affect productivity in order to: (1) decrease the amount of unpredictable variation, and (2) improve analyses of operations aimed at pointing out the areas for needed improvement.

Why will automeasurement be a necessity in the future?

Since the beginning of time, the productivity of people has been important. It is the productivity of people basically that determines the standards of living. It was the problem of productivity of people that Taylor dealt with in his early experiments. It is the productivity of machines and people that Industrial Engineers today currently deal with and will deal with in the future. We will find that productivity and increased costs will continue to be one of the foremost management

problems.

If we agree that time and productivity studies of people will continue to be vitally important, we must also agree that the Industrial Engineer must accelerate his developments in at least certain work measurement areas. We all recognize the importance of accurate time standards for purposes of incentives, cost estimating, and production planning and control. As stated before, I believe that work measurement techniques which were applicable in the past will not necessarily apply in automated mass production. Seldom do we consider work measurement in terms of the production process. I suggest that the failure to do so has been responsible for some of the difficulties we have experienced.

I would now like to show three slides which illustrate the difficulties of work measurement techniques in modern mechanized production. These pictures were taken from the automation article appearing in the March 19, 1956 issue of TIME Magazine.

(1) Here we see an automated Giddings & Lewis skin milling machine used to mill intricately contoured air foils for supersonic aircraft and guided missiles. All directions and instructions are supplied by the tape recording. I would like to direct your attention to the attendant shown in the picture. How shall we, the Industrial Engineers, using today's accepted short cycle technique of performance rating, rate this man's attention activity? Will right and left hand charts showing every reach and every grasp have an economic place in this picture? Do we propose to use laboriously prepared simo-motion charts of this man's non-cyclical random activity which is controlled almost entirely by external, seemingly unpredictable factors? What stopwatch techniques might we use in order to measure this man's analysis time, which in case of trouble will be his primary function?

(2) The next picture shows a Flight Simulator built by Bendix Aviation for U. S. Navy testing of electronic missile guidance systems. We see a crew of technicians at work with the equipment. Complicated operations of this type seem to defy the time-tested techniques of measuring short-cycle highly repetitive operations.

(3) Here we see a Jones & Lamson turret lathe. This lathe is controlled by instructions on punched tape. Even the attendant is missing from this picture. Where does the short cycle industrial engineering specialist fit into this picture? (end of slides temporarily).

These are only a few of the many examples that are with us today. Doesn't it appear that we must either modify our concepts to meet the changing conditions, or be prepared to join the thinning ranks of blacksmiths and harness makers? (4)

I submit once again that present work measurement techniques are sometimes

both inadequate and costly. Mechanization and instrumentation becomes a necessity if the engineering profession is to keep up with the mechanization of production facilities. Automeasurement allows a higher order of data processing as well as data collecting, and this higher order will be necessary for analyses of new operations which are not short cycle and highly repetitive.

Autoreasurement will also be of great value in the managerial field. A manager must be able to measure his performance in all key areas of a business. These measurements must be clear and rational, and must direct attention and efforts where they will do the most good. And these measurements must be timely.

Automeasurement will also serve an expanded concept of production control and process optimization. With much of our work controlled by equipment, our time study men could determine optimum speeds of machines to maintain the highest net productivity. Stopwatch time study is not very effective here. A tachometer, an ability to determine real reasons for delays, and knowledge of limiting factors which control machine speeds are more valuable.

Let's consider some of the fundamental methods, techniques and applications of our new concept of automeasurement.

First of all, I believe that all desired data should, wherever possible, be collected by automatic recorders. Examples of this are instruments which read and record running speeds, elapsed time, delays, production counts, material performances and other operating characteristics of the process, such as temperature, pressure, rate of flow, weight, current flow, and the like.

Another need will be the conversion of time study data to a form in which the methods of machine computation may be applied. Whenever attempts have been made to consider putting data on modern computational equipment a basic problem has always arisen. This problem deals with the cost of setting up the basic data in a form suitable for machine computation.

It is appropriate at this time to describe a machine that has been developed for us by International Business Machines Corp. When we originally conceived the specifications and requirements for the machine we dubbed it "WETARFAC", which simply means Work Element Timer and Recorder for Automatic Computing.

I would now like to show several slides in order to describe this first building block in our automeasurement laboratory.

(4) Here is a picture of the machine that IBM built. Now, what does this machine do? As previously stated, we believe that data collection must be mechanized. We believe that data processing must be done on mechanical computing equipment, and that the Industrial Engineer has to have a job structure that will permit him to exercise professional judgment a higher

percentage of the time. And to do this, he has to be relieved of the tedious routine of data collection and processing.

The Industrial Engineer is always faced with measuring the factor of time. It became evident that we needed a machine to measure time, the results from which could be piped into computing equipment now available such as the data processing equipment manufactured by IBM, available in our accounting division. WETARFAC is a machine capable of making time studies and producing its results in the form of five-channel paper punched tape which then can be fed into an IBM tape-to-card converter and reproduced in the form of a deck of IBM cards.

(5) This picture shows a piece of the five-channel tape.

(6) In this shot you see the tape coming out of the production recorder.

(7) Here is a picture of the tape-to-card converter in the process of transferring data from a tape to cards.

(8) Here is an IBM card that has been punched in accordance with the data on a tape. A deck of these cards can then be processed for data calculation in any manner that the engineer elects to program the data.

The next question you will likely ask is, how do we make a time study? At the present time the time study engineer feeds in his element codes, delay codes, rating factors, and frequency through a manual keyboard.

(9) Here is what the keyboard itself looks like.

(10) This is a picture of the engineer actually making a time study on the production floor using this equipment. We think that the WETARFAC is an exceedingly important device and are pleased that IBM has worked with us in this initial contribution to automeasurement. Their engineers and their applied science staffs have devoted many hours of their time to our problems. I think you will agree that it is important to be able to measure time in such a way that the data can be processed automatically. This is one element of mechanization that is fundamental to the auto-measurement concept. I believe you would also agree, however, that the requirements for the application of a device of this type will vary depending upon the production operation that we are trying to measure. For example, as Industrial Engineers we might look at a time study man doing the key punching of data on a certain operation and ask ourselves, can we automate the input of data into the WETARFAC and thus eliminate the job of time study technician?

We are working with developments to fit our own particular needs to cause feed-back from the machines themselves to enter the signals into the WETARFAC.

Toward this end we have designed and are building a time-counting device. This instrument will automatically accumulate and store multi-time

machine elements and element frequencies for future processing. With minor engineering changes this equipment can be used to automate WETARFAC, thus eliminating the technician.

However, each application of automeasurement differs. You must have the skill and ability within your own engineering staffs to know how best to use such a machine. It is not a pink pill, which if swallowed, will bring relief to your work measurement headaches on the following morning. You are not going to buy any machine that will build an automeasurement program into your own plant over night. It just isn't that easy.

(12) At Donnelley's we have made other important applications of automeasurement. An example of these is the control panel shown here which automatically records the small increments of no-work time at 24 stations along a conveyor. Time will not permit us to discuss other applications in detail today. Besides, most of these are only applicable to our own specific industry.

( ) The results of our efforts to automate work measurement have been very encouraging. We are now in the process of establishing a well-equipped automeasurement laboratory to provide the necessary equipment for our continual growth in the field.

We hope eventually to equip this laboratory with measuring devices that will measure all of the important factors of mechanized production which are necessary for an intelligent optimization study. We would like each of these measuring devices to eventually have certain common characteristics:

A. The collection of data should be automatic.

B. The read-out of the data should be in a form suitable for entry into a computer.

C. The various "automeasurement building blocks" should be capable of integration with each other in any combination necessary to solve any specific automeasurement problems.

D. The accuracy of the measurements should be within tolerances acceptable to the needs of each study.

E. The building blocks must be capable of simple interlock into production machinery for purposes of automatic recording.

Here are a few automeasurement building blocks we foresee as being necessary. You will add to this list yourselves as you analyze the needs for the better measurements necessary to optimize production and quality in mechanized production situations.

A. Time increments - We need to be able to measure increments of

time related to certain characteristics of the work process. This we can now do with WETARFAC. The data is ready for the computer. The input to WETARFAC, however, is still manual.

B. Weight

C. Count

D. Temperature

E. Current flow

F. Pressure

G. Color (particularly important in our industry).

Another characteristic of automeasurement is that it will call for broader applications of statistics. Mathematical statistics has been proven to be an effective and powerful tool for the handling of numerical data. Yet as Industrial Engineers we have failed to make extensive use of the elements of this science. We have not completely ignored statistics. It has been one of our tools and has been so recognized, but have we applied it scientifically? Certainly not to the degree it demands nor to the degree it is going to demand in the future.

A definite problem facing the profession is the education and training of Industrial Engineers to operate effectively in this new atmosphere. This will require changes in university curricula where the emphasis is on traditional techniques. Industry will have the mutual responsibility for training and orienting their engineers, new as well as established, for the needs of the changing productive patterns.

I would now like to discuss some of the ultimate goals of an automeasurement program. We have already tried to demonstrate the immediate aim of keeping time standard techniques in step with progress toward automation. We all recognize that industry needs accurate measures of its work pace, but I believe many additional by-products of automeasurement will result.

One of our goals is the proper utilization of engineering talent. This was mentioned before as an obstacle in our path. The engineer should bring to bear his skills and ability in analysis, judgment and interpretation, rather than spend his time in endless data collection and data processing activities. This goal will mean a greater utilization of talent on hand, and will lead to greater job satisfaction for the engineers in the profession.

Another by-product of automeasurement might be the consolidation of information concerning all the activities of the company. A management engineering analysis group can reduce information in all areas of the business to chart form, and present it to management for day to day decision making.

To summarize, let's review what we have said here. We have noted that up to now most of our emphasis has been placed on short cycle, repetitive operations. This resulted from our production oriented desire for job simplification as a means toward increasing productivity and reducing costs.

However, mechanization and automation has entered the picture. Its introduction is tending to force job enlargement due to its very nature. The short cycle, repetitive operation is the one most susceptible to becoming automated, which means that less and less people will be engaged in jobs of this type. The Industrial Engineer should recognize the importance of these changes since some of the areas which have been served by our techniques of the past will no longer need many of the services in work measurement that we offer today.

In order to meet this challenge, we too must automate. We must apply to our own Industrial Engineering methods the electronic controls, the mechanization and the feed-back principles that we are so energetically recommending for production processes.

Our data gathering and processing methods must be streamlined. We cannot apply the techniques that were unswayingly applied to the short, fixed, repetitive operation. We must turn our sights toward the science of statistics. Our data must become amenable to the automatic computer. Our non-professional tasks must be performed by machine; automatic computers must displace the slide rule and desk calculator. The chore-boy duties of the Industrial Engineer must be given to the electronic chore-boys of the future. This is not merely a nice idea -- this is essential for the survival of the profession.

No one is to transform all this for you. The success of tomorrow depends on your acceptance of this responsibility today. You must recognize the importance of automeasurement to industrial management and should sell management on the contribution that such measuring techniques can make to industry's basic objectives: cost reduction and increased productivity. The necessary research and development work will require active support of and participation by industry. You, as Industrial Engineers, must feel the responsibility for seeing that these needs are satisfied.

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* Circled numbers in margin indicate references to slides used to illustrate talk.

SOME APPLICATIONS OF PROBABILITY THEORY TO MANUFACTURING PROBLEMS

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The objective of this paper is to demonstrate the usefulness of probability theory in the solution of some problems encountered in manufacturing management. It is not intended to teach probability theory nor to provide rigorous demonstrations of the validity of the theory which is utilized. These latter objects could not be accomplished in the time alloted to this presentation. It is hoped, however, that the applications given here will provide a "feel" for the basic concepts involved and spur those to whom the ideas are appealing to further work in this area.

Uncertainty in Manufacturing

Probability theory has much to offer in the solution of management problems in manufacturing because uncertainty plays a large part in many decisions. For example, when a lot of some product is to be scheduled through several machining centers, it is common practice to do this using some pre-determined time which is in some way an estimate of the average time required. However, that an operation will take exactly the pre-determined time is the last thing one expects to happen. It is expected that it will take some time near this average, but standard practice does not provide for a statement of the amount of variation which is expected. If a schedule is determined based on this time, in a large proportion of the cycles the allowed time will be exceeded with subsequent repercussions on succeeding operations. Rules-of-thumb may be determined by experience to guide one as to how much time to allow in order to minimize delays, but an analytical treatment of the economic problem requires probability theory.

In scheduling production, formal recognition of the variation in worker attendance, accidents, breakdown of equipment, and quality of output, for example, just does not form a part of today's practices. However, these factors are important in determining the cost of production, and it is possible to consider them quantitatively in arriving at scheduling decisions.

In any situation where uncertainty plays a major role as a determinant in the economic problem facing a manager, probability theory and expected value can play an important part.

This paper will consider two general classes of economic problems in manufacturing which may be attacked using probability theory. The first of these classes includes problems where costs and/or savings are functions of a single probability distribution. The problem, for example, encountered in determining the number of items to stock or manufacture in the face of random demand for these items, of random variation in delivery times, or of random variation in reject rates. The second class of problems to be considered are those which involve supplying some kind of service in the face of random demand for this service over time. Here both the demand for the service and the rate at which service can be given may be random variables, and the economic problem is one of balancing the cost of additional service against the loss which arises from failure to provide this additional service. Such problems occur in manufacturing in connection with maintenance, the operation of automatic machinery, and materials handling, for example.

Probability and Expected Value

For purposes of the applications treated here, probability is defined as the relative frequency of an event. Given a finite event space within which are enumerated all the ways in which an event can occur, the probability of some desired event is the ratio of the number of ways this "successful" event can occur to the number of ways in which any event can occur, i.e., the total number in the given event space. All events in the event space are assumed to be equally likely. This probability of an event or set of events is, in most industrial applications, based on accumulated past experience modified by any specific knowledge available about the way in which the event is expected to occur in the future.

The expected value of some event is a weighted average of the ways in which the event can occur times the value of each occurrence. The weights are the probabilities of each event occurring. If a die is thrown, we expect (based on the geometry of the die) that the probability of a five coming up is 1/6. If one plays a game where the payoff is \$1 for a three or five and \$0 for any other number, the expected value of the game is

$$Ex = \frac{1}{6}(0) + \frac{1}{6}(0) + \frac{1}{6}(1) + \frac{1}{6}(0) + \frac{1}{6}(1) + \frac{1}{6}(0)$$

$$= \$.333$$

That is, expected value is the sum over all events of the product of the probability of occurrence of the event and its value if it does occur. Stated more formally:

$$Ex = \sum_i p_i V_i$$

where p_i is the probability of the ith event, V_i is its value if it occurs, and

$$\sum_i p_i = 1.$$

In the kind of problems which are discussed here, the objective sought will be the maximization or minimization of some expected value.[1]

The Inventory Problem

A classic example of the first type of problem to be considered is the case where a business firm must stock goods for a period during which the demand for these goods may be described by some probability density function as shown in Figure 1 [5].

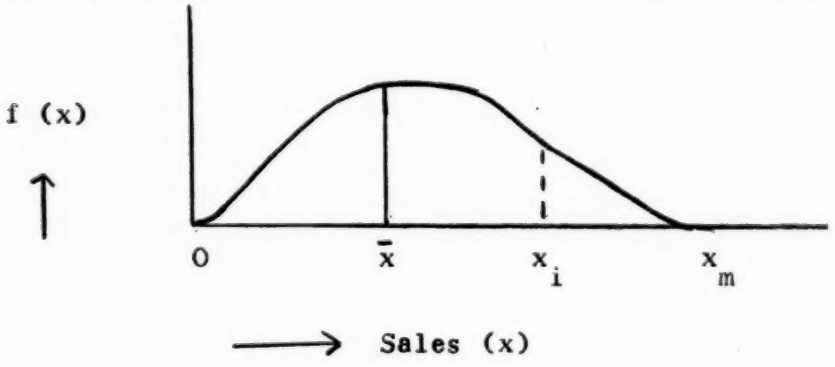

Figure 1

Here x represents the number of items which will be sold in the period, and f(x)dx the probability of finding x in the interval x to x + dx.[2] The expected number to be sold is $\bar{x} = \int_0^{x_m} xf(x)dx$ where x_m is the maximum number which can be sold in the period. Let

x_s = actual number sold

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1 This assumes a linear or constant preference for dollars.

2 A continuous distribution is used here as an approximation to the correct discrete distribution to allow for the use of integral equations. As long as x_i is large, no appreciable error is involved.

x_i = number of items stocked

P = profit per item sold in the period

L = loss if not sold in the period

Then for $x_s < x_i$, the profit would be

$$P(x_s) - L(x_i - x_s).$$

For $x_s > x_i$, the profit would be

$$P(x_i).$$

The expected profit is

$$Ex(\text{profit}) = \int_0^{x_i} P(x_s)f(x)dx - \int_0^{x_i} L(x_i - x_s)f(x)dx + \int_{x_i}^{x_m} P(x_i)f(x)dx \qquad (1)$$

Maximizing (1) with respect to x_i [3]

$$\frac{d(Ex)}{dx_i} = Px_i f(x_i) - L\int_0^{x_i} f(x)dx + P\int_{x_i}^{Xm} f(x)dx - P(x_i)f(x_i) = 0$$

$$= P - (P + L)\int_0^{x_i} f(x)dx$$

Thus, the condition for a maximum is

$$\int_0^{x_i} f(x)dx = \frac{P}{P + L} \qquad (2)$$

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[3] The differentiation of an integral containing a parameter in the limit may be accomplished according to

$$F(x_i) = \int_{a(x_i)}^{b(x_1)} f(x_i, x)dx$$

$$\frac{dF(x_i)}{dx_i} = \int_{a(x_i)}^{b(x_i)} \frac{\partial f(x_i, x)}{\partial (x_i)}\, dx + f(b, x_i)\frac{db}{dx_i} - f(a, x_i)\frac{da}{dx_i}$$

See Hildebrand, Advanced Calculus for Engineers. (New York: Prentice-Hall, 1948) p. 352.

Stated verbally, this says that one should order x_i units such that the probability of selling the ith unit or fewer is equal to the ratio of the profit per unit sold to the sum of this profit and the loss per unit not sold.

Happily, it is rarely necessary to go through the above kind of analysis in solving problems of this type. A marginal approach can provide one with equation (2) quite readily. Replot Figure 1 as a cumulative probability distribution as shown in Figure 2.

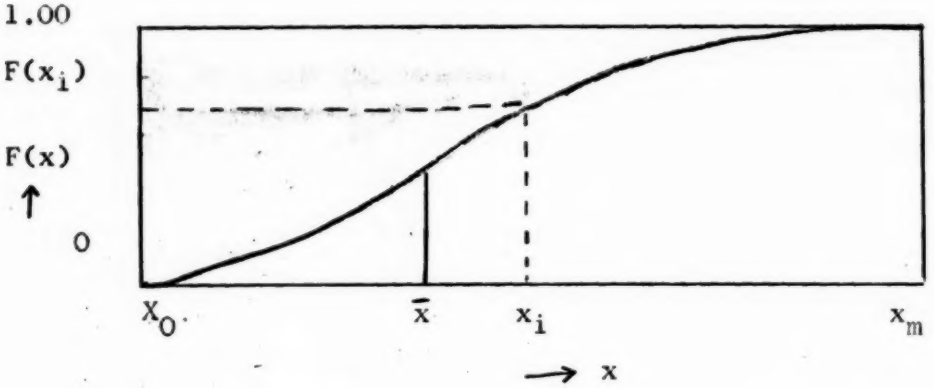

Figure 2

Here F(x) represents the probability of selling fewer than x units in the period. Then $1 - F(x_i)$ is the probability of selling x_i or more and $F(x_i)$ the probability of selling fewer than x_i. We will certainly keep adding units to our order (x_i) as long as the expected profit is greater than the expected loss, that is, until

$$P\left[1 - F(x_i)\right] = L\left[F(x_i)\right]. \qquad (3)$$

This equation of condition gives

$$F(x_i) = \frac{P}{P + L} \qquad (4)$$

which is identical with (2). Again, stated verbally, (4) says that one should increase the order size to the point where the ratio of the profit if sold to the profit plus loss if not sold is just equal to the probability of selling the order size or fewer.

In solving such a problem then, the cumulative probability distribution of sales based on past experience would be drawn as in Figure 2, P and L evaluated, and the optimum order size established by (4). While it is certainly true that the expectation determined by (4) either will or will not turn out to be true in any one period in which this policy is adopted, even if a decision is being made for a situation which will not be repeated, the prediction given is better than any other that could be made. This assumes that the sales experience given by the probability distribution will be repeated, assumes that the costs and losses associated with the decision are known, and assumes the maximization of expectation is an appropriate objective.

If goods are to be purchased for use in manufacturing at some steady rate, but delivery time is uncertain, a similar analysis may be applied. Here, the time for delivery is a random variable, and the problem is to set the reorder point at such a level as to balance the cost of running out against the cost of adding to the reserve stock. Assume delivery time may be given by the probability distribution of Figure 3. This indicates that the probability of delivery between t_0 and t_{min} is zero and this probability rises to one at t_{max}. Assume further that each day on which the firm is out of stock costs R dollars and each day's stock added to the inventory (by ordering earlier) costs C dollars for the period.

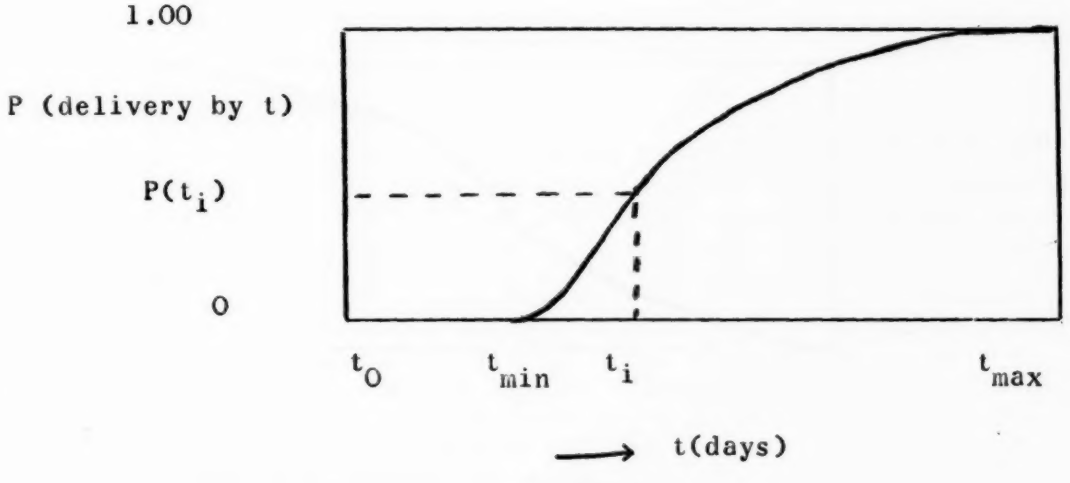

Figure 3

Then the problem is to increase the reorder period so as to just balance these costs. In this case

$$C = \left[1 - P(t_i)\right] R$$

$$P(t_i) = \frac{R - C}{R} \qquad (5)$$

Thus the cost of an additional day's supply is just balanced by the expected cost of running out when the probability of delivery is equal to the ratio of the cost of running out less the cost of an additional day's supply to the cost of running out.

An additional problem of interest in manufacturing is that of determining the number of units to start through some process when some given number of good units is necessary and there is a probability distribution associated with the fraction of defective items from the process [1]. If experience is tabulated in the form of the frequency with which a given ratio of pieces started to good pieces results (in order that the effect of different size of orders be canceled out), a distribution such as that shown in Figure 4 would be obtained. Then the ratio of pieces started to good pieces is a variable x which must be equal to or greater than one. Assume that the variable cost of each piece started is V and the

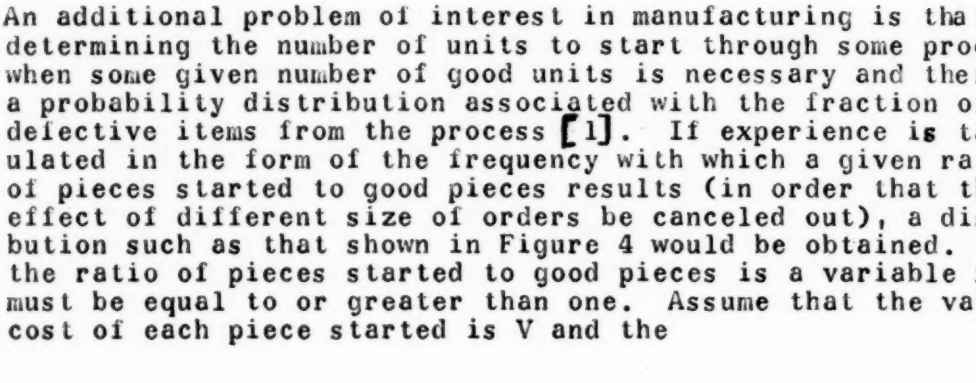

Figure 4

additional set up cost which will be incurred if not enough good pieces result is S. Then the expected cost of adding the ith piece to the manufacturing order is $P(x_i)V$ (V will only be an added cost of the order if the piece is not needed). The additional set up cost will be incurred if the start/good ratio at the ith piece is not large enough. The probability that the (i+1)th piece will be necessary is $\left[P(x_{i+1}) - P(x_i)\right]$. Thus

$$V\left[P(x_i)\right] = S\left[P(x_{i+1}) - P(x_i)\right]$$

and

$$\frac{P(x_{i+1})}{P(x_1)} = \frac{V + S}{S} \qquad (6)$$

In each particular case, the start/good ratio would be converted into units appropriate to the number of good pieces desired and pieces added to the starting order until the ratio of $P(x_{i+1})/P(x_i)$ was equal to the ratio of the sum of the variable cost per piece plus the set up cost to the set up cost.

The problems treated thus far have all dealt with a single probability distribution and are of essentially the same economic character, although they differ in detail. Now we turn to a second class of problems which deal with uncertainty where probability theory may make an important contribution -- servicing problems.

The Servicing Problem

The economic problem associated with servicing situations may often be given as one of minimizing the sum per unit served of the cost of lost output and the cost of providing service as the level of service is varied. As more service is provided, less output is lost due to the ability of the servicing facilities to render service sooner on the average after it is required. However, this addition of service, which costs something, decreases in its ability to produce savings in terms of increasing output until at some point the sum of the costs is a minimum. One's ability to determine this optimum point is a function of the ability to predict that part of the total lost time which is avoidable and determining the cost of this time to the firm.

The Waiting Time

Waiting time is occasioned by a demand for service when such service is not available due to the fact that all available

servicing facilities are busy. The prediction of its amount depends then on the probability of a call for service and the probability that the servicing facility(ies) are busy with prior calls. The first of these probabilities is predictable in a general sense, while the second is conditioned on the fact of a call or calls having arrived and the servicing requirements imposed by the call.

The Probability of a Call for Service

The probability of a call for service from a unit in the population in question may be worked out by postulating an event space as shown in Figure 5, [2], [3], [6].

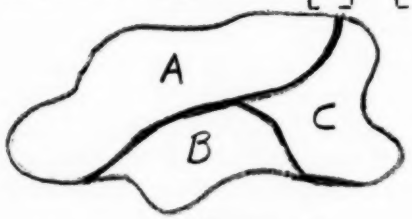

Figure 5

In Figure 5, A is the probability that a call for service occurs between O and T, B is the probability of a call for service after t + dt, and C is the probability (small) of a call for service during dt. Then we define the following functions:

$$p(t) = \frac{C}{A+B+C}$$

= probability of a call for service during dt.

$$P(t) = \frac{A}{A+B+C}$$

= probability of a call for service between O and t.

$$\beta(t) = \frac{C}{B+C}$$

= probability of a call for service during dt, given that the call did not occur between O and t (I = O)

Since the sum of A, B, and C must be unity

$$p(t) = C$$

$$P(t) = A$$

and

$$z(t) = \frac{C}{1 - A}$$

$$= \frac{p(t)}{1 - P(t)} \qquad (7)$$

Since

$$p(t) = \frac{d\,[P(t)]}{dt} \qquad (8)$$

then

$$z(t) = \frac{\frac{d\,[P(t)]}{dt}}{1 - P(t)} \qquad (9)$$

and integrating

$$\int_0^t z(t)dt = -\ln\,[1 - P(t)] \qquad (10)$$

The probability given by $[1 - P(t)]$ is the probability that the unit in question will not require service until at least t. This, then, is the probability that the unit will run a time equal to t or longer. Calling this $P_0(t)$

$$P_0(t) = e^{-\int_0^t z(t)dt} \qquad (11)$$

If the unit or set of units is given service each time it calls, the system will reach a state of statistical equilibrium and the calling rate $z(t)$ will be a constant λ.

Then

$$P_0(t) = e^{-\lambda t} \qquad (12)$$

Thus, the probability of a unit or set of units running at least t before giving a call for service is exponential and the mean running time between calls is $1/\lambda$.

The probability of no call for service occurring during dt is

$$1 - p(t) = e^{-\lambda dt}$$

and

$$p(t) = 1 - e^{-\lambda dt}$$

Expanding,

$$1 - e^{-\lambda dt} = \lambda dt - 1/2(\lambda dt)^2 + \ldots$$

Neglecting higher order terms,

$$p(t) = \lambda dt \qquad (13)$$

Then the probability of no call for service between 0 and t and a call during dt is

$$P_0(t) \left[p(t)\right] = e^{-\lambda t} (\lambda dt)$$

and thus

$$z(t) = \lambda e^{-\lambda t} dt \qquad (14)$$

which is the density function which describes the condition of interest, the fact of a call for service in exactly t.

The cumulative probability distribution of equation (12), for example, may be used to determine the expected time to failure of a piece of equipment made up of several components whose individual reliability is known. A unit whose components include 10 relays each of which has an average time to failure of 2000 hours would have a reliability described by

$$P_0(t) = e^{-n\lambda t}$$

$$= e^{-10\left(\frac{1}{2000}\right)t}$$

$$= e^{-\frac{t}{200}}$$

assuming that no other components contributed to its breakdown. Thus, the probability of the unit surviving for 200 hours is 0.37 and for 2000 hours is 0.00005. If the unit were made up of different kinds of components with different reliabilities, then

$$P_0(t) = e^{-t\sum_i n_i \lambda_i} \qquad (15)$$

The above kind of probability analysis assumes that calls for service are primarily due to chance and not to wearout. For many kinds of equipment wearout does not become an effective cause of failure until late in life, and much equipment is maintained so as to minimize wearout as a cause of failure. "Service calls" other than failure type most often are due to some system of chance causes operating over time. Since with any reasonable preventive maintenance and in the presence of human operators, chance causes are by far predominant as a cause of service calls, the distributions derived are the most useful general type in servicing situations [2].

The Distribution of Service Times

In order to determine waiting time, it is also necessary to know something about one's expectation as to the duration of service times, since waiting time occurs when a unit has called for service, and the service time interval for units which gave prior calls is such that no servicing facility is available. If the same assumptions could be made about the distribution of service times as was made about calls, that is, that at any time the probability of a service interval ending (call arriving) was not dependent on how long the service interval (running interval) had lasted until that time, then

$$P_s(t) = \mu e^{-\mu t} dt \qquad (16)$$

where $P_s(t)$ is the probability of a service interval lasting exactly t, and $\frac{1}{\mu}$ is the average service interval.

While the assumption that service intervals are distributed individually and collectively at random does not seem plausible since the amount of time until a service interval ends is certainly in some way dependent on how long it has already lasted, yet in many situations an exponential distribution seems to describe the data quite well. If this distribution holds, then the problem of determining waiting time is not nearly so difficult as for any other case including that of a constant service time. In any case, a knowledge of the shape of the service time distribution is essential to the determination of waiting time.

The Transition Probabilities

In order to compute waiting times, it is necessary to describe in terms of the given probability distributions of the servicing system, the states in which the system may find itself and the ways in which it may go from one state to another. For example,

in the case of a group of units serviced by a single facility, the system may be characterized by λ and μ where these are the same for all units. The system may be in state E_0 when all units are working and E_j when j units are down for service. The system may go from $E_j \longrightarrow E_{j+1}$ when a unit among those working $(n - j)$ calls for service. It can go from $E_j \longrightarrow E_{j-1}$ when a unit in service goes back into operation. The probabilities of these transitions are given by the distributions of which λ and μ are parameters and the system can be described by a set of differential equations which can be solved for the expected value of the waiting time.

Even in this simplest case, the computations involved are quite lengthy if the number of machines is at all large, and especially so if the economic problem involves trying several alternative servicing policies. If the distribution of service times is other than exponential, the computational difficulties are even more pronounced. Therefore, in most cases, practical results from the use of this probability concept depend on tables and graphs which give general solutions to the problem. Fortunately, some of these are available and more are in the process of computation.

The range of servicing situations which must be covered computationally is, fortunately, not too large. Calls for service may originate from a small population such that the arrival of a call changes appreciably the size of the calling population. Here, the transition probabilities as described above must be given and the system solved for all state probabilities. If the calling population is quite large, an average calling rate can be used to describe the situation regardless of the number of units being serviced or waiting. The situation then can be solved for its equilibrium conditions.

In both the above cases single or multiple servicing may be contemplated, and the servicing rate may be constant or at random. In addition to specifying all the above aspects of each situation, the priority system in effect must be known. Most general mathematical formulations are based on a "first-come, first-served" rule, but some other kinds of priority systems have been treated [7].

In order to illustrate the economic usefulness of this servicing concept, some problems will be worked out.

A Toolsetter Assignment Problem

The first case to be considered involved automatic machinery where no operators are required for the machines, but the tool set-ups

require adjustment or repair at random intervals. For this purpose a toolsetter is assigned to a number of machines and the problem of economic assignment arises. Assuming that the firm's objective is to minimize the cost of a given level of output, it would be possible to have various combinations of toolsetters and machines to produce this output. All costs of attaining this output may be assumed constant except the cost of idle machine time (which is avoidable) and the cost of the toolsetters. As the assignment is increased, the amount of idle machine time per machine increases and more machines must be available to give the desired output. At the same time the toolsetter cost per machine goes down. The optimum assignment point and the output per machine at this assignment may be determined by solving for waiting time and machine running time for each possible assignment and adding up the costs incurred.

During a period of one year 418 toolsetter calls were experienced from 20 machines. Since 38,000 running hours were involved, the average running interval between calls was 38000/418 = 90.9 hours. From this λ = 1/90 9 = 0.011 calls for service per running hour per machine. Calls, then, were assumed to occur according to equation (14).

The distribution of service times for these 418 calls is shown in Figure 6. The mean length of service time was 180 minutes giving a servicing rate, μ, of 60/180 - 0.333 per hour per toolsetter. The distribution is not a pure exponential and its coefficient of variation is computed as 0.805. Tables of waiting time and machine time for both exponential and constant service times are available, [4], [6], and values for other service time distributions can be obtained by interpolating according to the square of the coefficient of variation of the distribution. Waiting and machine times used here were obtained in the latter manner.

The cost of a machine was determined as $1500/year where this is the annual average of capital and operating expenses. Since this is the cost which would be incurred if more machines were required because of lower utilization for an increased assignment, the cost of waiting time per hour for a 2000 hour year is $0.75. Toolsetters' wages including fringe benefits average $3.00/hr. On this basis the variable cost of output per machine of any given assignment may be determined from

$$\text{Variable Cost} = \frac{wC_w + C_r/n}{m} \qquad (17)$$

THE DISTRIBUTION OF 418 CALLS
FOR SERVICE

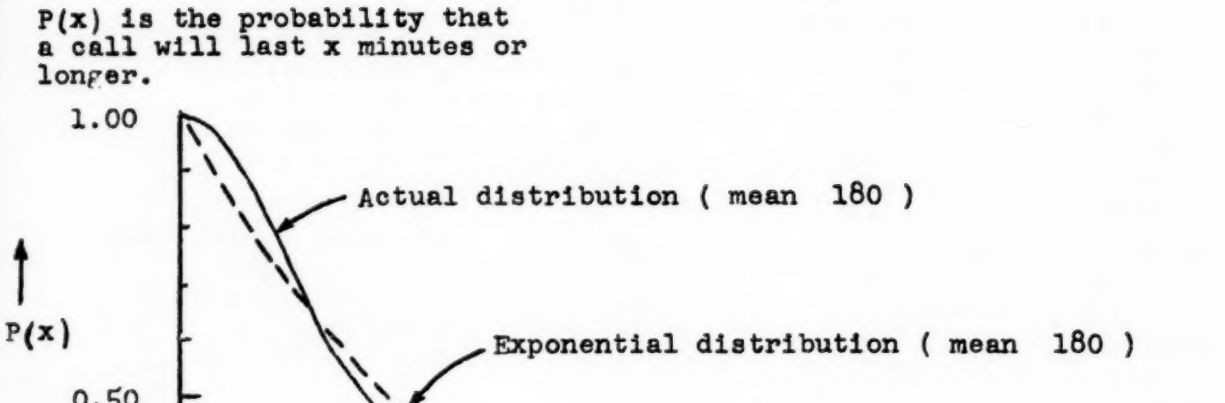

Figure 6

Where

w = average waiting time per machine

m = average machine utilization

C_w = cost of machine waiting time

C_r = toolsetter's wages

n = number of machines assigned

Division of the cost by the average machine utilization may not appear obvious but must be done to account for the fact that different assignments give different levels of output per machine and it is the cost of output which is to be minimized.

The solution of (17) for various assignments is shown in Table 1 and gives a minimum variable cost at n = 24. In the given situation, the output of 200 machines running continuously was required to give the necessary production, and an assignment policy of 20 machines per toolsetter was in force. To get 200 full time machines with this assignment 200/.934 or 214 must be operated calling for 11 toolsetters. With an assignment of 24 machines, 200/.918 = 218 machines must be operated calling for 9 toolsetters. The total variable cost of the present policy is therefore 214 (1500) + 11(3) (2000) = $387,000 per year. The cost of the new policy if instituted would be 218 (1500) + 9(3) (2000) = $381,000 per year. The difference of $6000 per year is due to the better balance achieved between machines and toolsetters. Clearly such a result could have been achieved by experimenting with various assignments, but only at a cost very likely in excess of the given savings. The solution of the problem using this method is the matter of an hour's work given the service requirements and cost information.

n	w	m	$\frac{wC_w + C_r/n}{m}$
20	.034	.934	.188
23	.046	.921	.179
24	.051	.918	.177
25	.058	.912	.179
30	.097	.875	.198

Table 1

Group Servicing

In some situations, a group of servicing facilities may jointly serve the same calling population. One such situation arises in the production of canvas footwear in connection with sewing machines. In one firm, five mechanics are currently assigned to service a group of 100 sewing machines. Whenever a machine breaks down or requires adjustment, the operator signals a clerk who assigns a maintenance man. Operators are paid on a piece rate and when their machine is being serviced or waiting, they revert to an hourly rate. The management desires to eliminate waiting time, insofar as possible, and the current assignment does this. The question arises here as to the price being paid to accomplish this objective.

Over a period of eleven days, the average number of calls per day was 27 and the average service time 36 minutes. The coefficient of variation of the service time distribution was found to be unity and thus an exponential distribution was assumed. Under these conditions, λ was approximately $27/8 \times 100 = 0.033$ and μ, $60/36 = 1.67$. The servicing constant, $\lambda/\mu = 0.02$. Calculation of the expected values of waiting time, machine utilization, and operator utilization, resulted in the values given in Table 2. Two mechanics could just handle the load if calls occurred at perfectly regular intervals and if service times were constant. With just two mechanics, any variation in either calling interval or servicing time gives rise to some waiting time which can never be made up. And therefore, the situation will stabilize at some lower number of machines. With the present assignment of five mechanics, each machine can be expected to wait for a mechanic three-hundredths of one per-cent of each hour. The addition of the fifth mechanic at a cost of $2.24 per hour resulted in a decrease in waiting time of approximately one-tenth of one per-cent per hour and an increase in machine time of very close to this amount. In order for this addition to have been economic, the company must have evaluated waiting time at in excess of $22 per hour. Looked at another way, the increase in machine utilization was 0.001 per machine per hour or 10% of one machine per hour for the group of machines. The cost of this was the mechanic's wages. Since by no stretch of the accounting system could either cost be justified, the addition of the fourth mechanic was examined.

Number of Mechanics	Waiting Time Per Machine	Machine Utilization	Mechanic Utilization
3	0.0070	0.973	0.650
4	0.0014	0.979	0.490
5	0.0003	0.980	0.393

Table 2

Here, the saving in waiting time is 0.56 per cent of an hour giving a value to waiting time of approximately $4 per hour. The increase in machine utilization is 0.006 per machine per hour or about 60% of one machine added to the production capacity of the group of machines. At $2.24, this last was just considered a reasonable price when coupled with the fact that workers would almost never have to wait for service, a psychological advantage of some importance.

Conclusion

The above examples have demonstrated some uses of probability theory in the solution of management problems. It must be recognized that the situations treated are of the simplest kind and their treatment perfectly straightforward. Most situations are more complex than these and their treatment may involve both elaboration of method and simplification of structure in order to be treated formally.

In a large number of cases involving several probability distributions and alternative policies, simulation of experience by Monte Carlo provides the best answer. However, it is essential that the analyst be able to frame a problem involving uncertainty in a formal manner even though he must resort to approximate solutions. Only in this way is one enabled to understand and evaluate the technical and economic structure of the model which is to be solved.

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ORGANIZING FOR INDUSTRIAL ENGINEERING

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In preparing this paper I am interpreting that organizing for industrial engineering includes functions, departmental organization, staffing, and administration.

Organizing for industrial engineering is no different from organizing for any company function: the same accepted principles of organization must be applied. Since we today are not concerned with the theory of organization as such, any of you who want to catch up on that subject should refer to one of the many excellent texts on the subject.

In simple outline, the organization of an Industrial Engineering Department demands three steps:

1. The authority, responsibility, and accountability of the department must be clearly defined.

2. The department must be integrated in the company plan of organization.

3. Every provision must be made so that the department can effectively perform its assigned tasks.

In administering the department, the Chief Industrial Engineer should, of course, strive to have a well-knit, smoothly functioning unit. His operating plan must also enable him to provide all the services expected of his group.

With this introduction to the general problem, let us now examine the subject closely. To that end this paper is divided into the following main sections:

1. The role of industrial engineering in business today.

2. Working relationships with other departments and divisions.

3. Place of Industrial Engineering Department in company organization structure.

4. Internal organization of Industrial Engineering Department.

5. Industrial engineering personnel.

6. Departmental administration.

7. Getting action on recommended programs.

I. THE ROLE OF INDUSTRIAL ENGINEERING IN BUSINESS TODAY

Before approaching the task of organizing an Industrial Engineering Department, one must have a clear idea of the nature of industrial engineering in business today. In almost all companies the Industrial Engineering Department is a service department to the operating departments of the Production Division. (Throughout this paper, sales, finance, engineering, and production are referred to as "division"; these divisions are made up of departments.)

Since it is staffed with men of specialized background, experience, training, and interest, the Industrial Engineering Department may also provide special services to other-than-production departments.

A glance at the table of contents of any book on the subject will show the wide variety of activities an Industrial Engineering Department can perform. Rarely, however, does any individual company's department do more than a part of those listed. The scope of its activities in any company is a deciding factor in determining where to fit it in the company plan of organization and how to organize it internally. Equally important considerations are the nature of the services provided and the organization plan of the company.

THE INDUSTRIAL ENGINEERING APPROACH

In carrying out its functions, the Industrial Engineering Department uses what is sometimes referred to as the "scientific approach" - in other words, the industrial engineer gathers and analyzes facts, forms tentative conclusions, compares and tests the alternatives, and finally reaches and presents his findings, conclusions, and recommendations.

It is a common fallacy to assume that all activities that lend themselves to this approach automatically fall within the province of the Industrial Engineering Department. It is also wrong to assume that the industrial engineer is the only one who can apply these techniques successfully. This same approach is used by many other specialists.

AUTHORITY EXERCISED BY INDUSTRIAL ENGINEERING DEPARTMENT

In dealing with line and staff departments, the Industrial Engineering Department exercises functional, not line, authority. In an A.M.A. Research Report, Marvin Bower explains the distinctions between the two as follows: "The executive with line authority says 'do'; the executive with functional authority says 'if and when you do, do it in this way.' The line executive determines the need, timing, and place for action, while the executive with functional authority determines the method.*

As members of a service department, the industrial engineers solve special problems and perform continuing work for operating departments. They should not be permitted to order the adoption of a method, the purchase of a specific item of equipment, the installation of an exact time standard; they should only recommend to the line supervisors that the action be taken. This is functional authority. Naturally, the Chief Industrial Engineer has line authority over all operations within his department.

BASIC OBJECTIVE OF AN INDUSTRIAL ENGINEERING DEPARTMENT

The basic objective of an Industrial Engineering Department is usually twofold: (1) to establish methods for controlling production costs and (2) to develop programs for reducing those costs; both the methods and the programs are instituted by line management.

In most cases the Industrial Engineering Department exists primarily to provide specialized services to the Production Division. Other divisions may use its services infrequently or extensively. Should their demands consistently be at a high level, it is often advisable to set up service departments in the other divisions so that Industrial Engineering can concentrate on its primary responsibility to the Production Division. If this step is taken, formal organizational relationships between the service departments are seldom necessary since they will have very little in common beyond a uniform approach to problem solving.

II. WORKING RELATIONSHIPS WITH OTHER DEPARTMENTS AND DIVISIONS

An understanding of the nature and functions of industrial engineering is an essential preliminary to any treatment of departmental organization. By the same token one must also understand the working relationships such a department customarily

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* A.M.A. Research Report No. 20

maintains with other departments and divisions. Only then can the organizational place and structure of the Industrial Engineering Department be properly determined.

In examining the working relationships of the Industrial Engineering Department with non-production departments or divisions or with departments within the Production Division, one finds no single, universally accepted pattern - at least I didn't. Not only do the working relationships vary from company to company but also from department to department within the same company. One does, however, find a fairly uniform set of standards that guide all Industrial Engineering Departments. These are:

1. The department must recognize and fulfill its proper role.

2. It must see that its work ties in with all company operations.

3. Where the effects of its recommendations reach beyond the area studied, the department must weigh those effects and act accordingly.

4. The department must approach each problem objectively.

5. The industrial engineering staff must conduct itself in a manner to ensure the acceptance of its services.

Each of these points or standards is important enough to the operation of an Industrial Engineering Department to justify further consideration here.

INDUSTRIAL ENGINEERING MUST RECOGNIZE ITS ROLE

As a service arm to other departments, Industrial Engineering must measure its success on how its work is accepted and what action is taken on its recommendations. It can greatly influence its standing by adhering to these simple rules:

1. Respect line management's authority. A line supervisor usually has what he considers sound reasons for running a department the way he does. To ensure his continuing administrative success, he should be the only man with line authority over his group. The Industrial Engineering Department must get its programs adopted through him just as a superintendent must issue orders through the foreman.

Should the line manager and the industrial engineer disagree on the program or its timing, their common superior should hear the

facts on both sides. It is unsound for the Industrial Engineering Department to have or to use line authority to get its services accepted or its recommendations enacted.

2. Supplement line management. The Industrial Engineering Department must never become a substitute for line management. Sometimes, through its own excess of zeal or through default of line authority, Industrial Engineering takes on projects or routine activities that should remain with line management. Although this may temporarily enhance the department's importance and indeed make it seem indispensable, it soon weakens line management, and in the long run harms operations.

To avoid this, the Industrial Engineering Department should continuously strive to get line management to perform all activities possible. It should enter the scene only when line management truly needs the industrial engineer's specialized training, background, and knowledge.

3. Gain the cooperation and good will of the departments served. Often when the Industrial Engineering Department works on a problem, the department served feels that "outsiders are horning in." This hostility is born of distrust and misunderstanding of industrial engineering's real function. To counter it, the industrial engineer must do all in his power to gain the confidence and enlist the support of workers and supervisors in production departments. Once they understand what the Industrial Engineering Department is trying to do and how its work will benefit the company and them, they will be quick to appreciate and accept the services offered.

4. Adapt its services to the needs of the department being served. By background, training, and experience the members of the Industrial Engineering Department are qualified to solve a variety of production problems by following an orderly pattern. Although they should use this asset to advantage, they should not use it blindly. A method of attack or a solution that is successful in one department may fail in another even though the problems are almost identical. The reason may be that the supervisor of the second department - or the department itself- is totally different in attitude or capability from the first. Recognizing these variances, the Industrial Engineering Department must adjust its working methods to fit the needs and capacities of the department receiving its services.

THE DEPARTMENT'S WORK MUST TIE IN WITH ALL COMPANY OPERATIONS

The Industrial Engineering Department has a responsibility for ensuring that the work it performs and the recommendations it

presents tie in with company operations. This requirement holds true even when the department's scope of activity is limited to the Production Division. Specific examples of the need to tie in work with other-than-production divisions are cited below:

1. Financial Division. In its work within the Production Division, the Industrial Engineering Department must recognize the procedures and requirements of the Financial Division in the following circumstances:

a. In helping operating departments to prepare annual budgets, the department must adhere to prescribed procedures and format.

b. Proposals for capital investments or large expense items must follow prescribed procedures.

c. Wage incentive proposals must be adaptable to proper, low-cost, payroll preparation. Payroll preparation procedures should provide, as a by-product, control data by which the Industrial Engineering Department and the production department involved can follow the operation of the wage incentive program.

d. The source data and reporting procedures used to provide information for Industrial Engineering should, where possible, be identical to those required for accounting controls.

2. Sales Division. As a result of services to the Production Division, the Industrial Engineering Department may affect the Sales Division in the following ways:

a. Proposed changes in production-lot sizes may shorten stock-replenishment cycles and permit the quoting of shorter customer-service periods.

b. Changes in warehouse layout, equipment, or materials handling may modify the time required to assemble, pack, and ship products, thereby reducing order-fulfillment times.

c. Changes in quality attainment may permit premium pricing in part or all of a product group, the opening of new markets, and so on.

3. Industrial Relations Division. Industrial Engineering must work closely with the Industrial Relations Division where these subjects are concerned:

a. Changes in methods may eliminate the requirements of certain crafts, create the need for specialists, or call for other adjustments in the labor force. All technological changes vitally interest the Industrial Relations Division.

b. The Industrial Engineering Department should be consulted on the programs to be presented and the [illegible] used in wage incentive clauses at labor-management [illegible].

c. Industrial Engineering must notify the Industrial Relations Division of methods changes that affect job evaluation.

d. Where necessary, Industrial Relations may ask the Industrial Engineering Department for facts on labor grievances.

4. Product Engineering Division. The Product Engineering Division and the Industrial Engineering Department will share common ground in these cases:

a. When capital expenditures are proposed for equipment and plant, both groups will be interested in arriving at economic pay-outs.

b. Product Engineering will be greatly concerned about the production costs of various product designs.

c. The two groups will ordinarily collaborate in developing lowest cost tooling.

d. If Maintenance is organizationally a part of the Product Engineering Division, it may work in concert with the Industrial Engineering Department to develop programs for increased productivity, training, application of wage incentives, and performance and cost controls. (If Maintenance Engineering is organizationally a part of the Production Division, it will be served in these respects along with other production departments.)

THE DEPARTMENT MUST WEIGH COMPANY-WIDE EFFECTS OF ITS RECOMMENDATIONS

Beyond the specific and obvious responsibility of the Industrial Engineering Department to tie in its work in the Production Division with other divisions is its responsibility to recognize how the effects of its recommendations may reach beyond the area studied. The operating divisions are concerned with regular planning and execution of agreed-upon company programs; each division plays a well-understood part. The Industrial Engineering Department, however, is for the most part an advocate of change. When it recommends changes in the Production Division, it must anticipate the probable consequences of these changes for other divisions. This point is emphasized for two reasons:

1. The action recommended in a production department may open up improvement possibilities in other divisions. Sometimes, of course, these secondary improvement possibilities turn out to

be rather unimportant. Often, however, they can lead to dramatic changes that not only benefit the non-production department but reinforce the action taken in the production department.

2. Occasionally the value of an apparent improvement in the Production Divisions may be more than offset by the problems and additional costs it will create in another division. Sometimes the bad effects can be erased by modifying the recommendations; at other times the recommendations will not be made.

THE DEPARTMENT MUST APPROACH EACH PROBLEM OBJECTIVELY

Earlier I have stressed that Industrial Engineering is a service department supplying manpower with special training, experience, and talents for solving problems in the Production Division. How it provides these services is equally important as the services themselves.

To ensure that the actions it recommends are beneficial to the company as a whole and have a good chance for adoption, the Industrial Engineering Department must operate with as much objectivity as possible. Three suggestions here will illustrate how that objectivity may be put into practice:

1. In approaching a problem, the Industrial Engineering Department must listen to and evaluate objectively the viewpoints of all the departments affected. In making recommendations, it should support its elected course of action by sound reasons proving that the proposal submitted offers the best possible solution.

2. The industrial engineer must be prepared to meet prejudiced points of view and to treat them understandingly but firmly. If the department has succeeded in gaining the confidence of line management, the engineer should be able, by his objectivity, to explain why the prejudice is ill-founded. He should never, of course, ridicule or expose the prejudiced man.

3. Although the Industrial Engineering Department must never arbitrarily disregard the opinion of line management, it should not lose sight of the fact that its first concern is to strengthen the over-all operations of the company. This may sometimes require the department to act contrary to the wishes of production supervisors.

CONDUCT OF DEPARTMENT MEMBERS IMPORTANT TO THEIR SUCCESS

Industrial Engineering can materially enhance its standing in the company by the conduct of its staff. Here are some hints on promoting good relationships with line personnel:

1. Recognize the service role of the department. Members of the Industrial Engineering Department must recognize that they hold a unique position in the company. As trouble shooters with special training, their work usually calls for upsetting the status quo. Since that may be an unpopular assignment, the successful industrial engineers must build confidence, take care not to disparage production efforts, and observe department protocol if they wish to be accepted by line management.

2. Steer clear of company politics. An industrial engineer is occasionally assigned problems loaded with "political" implications. In such a case it is important for him to be completely objective both in attitude and in action. Any other course will jeopardize his future acceptability and effectiveness.

3. Respect line management's prerogatives. In his service capacity, the industrial engineer must work through line supervision. Before undertaking a study in any department, he must see the supervisor or foreman, explain the purpose of his study, and solicit assistance. The department supervisor should be made a part of the project, should select the men and equipment to be observed, and should give all orders to departmental personnel necessary for the conduct of the study.

4. Give proper credit for contributions. The industrial engineer should be quick to give others credit for contributing to the development of sound recommendations. Such recognition does not detract from his own reputation as an "idea man"; on the contrary, it enhances his standing. It gives him a reputation as a catalyst. It will also make his work easier, for operating men will come to him more readily with good suggestions.

III. PLACE OF INDUSTRIAL ENGINEERING DEPARTMENT IN COMPANY ORGANIZATION STRUCTURE

With this review of the nature of the Industrial Engineering Department, its responsibilities, and its working relationships within a company, we can now consider where it belongs in the organization structure. One guideline might be mentioned here, obvious though it may seem: the Industrial Engineering Department should report to the executive who has line responsibility for the departments it regularly serves. Thus if a Vice-President for Operations is responsible for coordinating research, engineering, production planning, sales, quality control, personnel, and so forth, he should probably have Industrial Engineering, too. If, however, there is a Manufacturing Manager to whom production activities report, the Industrial Engineering Department should then also report to him.

That guideline admits many interpretations, for practically speaking there can be no hard and fast rule governing the place of Industrial Engineering in the organization structure of all companies and plants. To learn what forms are in effect today, we asked this question of a number of companies: "To what executive does the Industrial Engineering Department report, and what other executives are on the same level as that executive?" At the same time an explanation was sought of any line or functional direction in the Industrial Engineering Department received from any other executive, from a headquarters industrial engineering group,etc.

Although the review showed no single, typical position in the organization structure for the Industrial Engineering Department, it did point up the factors that influence its position. These are: (1) the number of direct-labor employees, (2) the scope of industrial engineering activities, (3) the complexity of manufacturing operations.

1. Number of direct-labor employees. The formal recognition of Industrial Engineering as a full-time activity grows as the number of employees grows; at the same time, however, its organizational rank seems to become lower.

In the small companies it was indicated that the top manufacturing man did all the industrial engineering that was done, in addition to his other duties, and that no formal department existed.

In companies of 300 to 500 employees the men performing industrial engineering activities reported variously to Executive Vice-Presidents and Production or Operations Vice-Presidents. In these cases, the Chief Industrial Engineer was on the same organizational level as the Superintendent and Chief Product Engineer (but not necessarily considered so important).

In companies with 600 and over hourly paid employees, Industrial Engineering was formally recognized as a department and occupied a lower place in the organization plan. In these companies the chief manufacturing executive did not have authority over engineering, quality control, and other activities, which are often grouped under one executive in smaller companies, and the Industrial Engineering Department reported to a Factory Manager, Works Manager, or Superintendent.

2. Scope of industrial engineering activities. The activities of the Industrial Engineering Department influence its place in the organization structure to this extent: it reports to the executive who is responsible for the departments in which it does the bulk of its work. In most cases, however, it provides some services to other departments.

3. Complexity of manufacturing operations. The review showed that as manufacturing operations grew more complex, the size of the Industrial Engineering Department increased but the scope of its activities decreased, - more attention went to strictly production problems. The increase in complexity of manufacturing operations and the corresponding growth of the department usually meant that Industrial Engineering reported at lower organizational echelons than it did in companies with less complex production operations.

IV. INTERNAL ORGANIZATION OF INDUSTRIAL ENGINEERING DEPARTMENT

In reviewing a representative number of companies to determine what activities the Industrial Engineering Department performed and how it was organized internally for the job, we found that where the Industrial Engineering Department had a formal internal organization, it followed one of two distinct patterns, each bearing in its own way on the activities performed. In one case the activities themselves determined the pattern; in the other, this depended upon departments served. Most companies, however, freely assigned groups of engineers on a special project basis.

GROUPING OF RELATED FUNCTIONS

Under this plan the Industrial Engineering Department is divided into sections, each responsible for related functions. For example, work relating to time study may be in one section, methods work in another, and so on. For the most part the members of a section work regularly on all the activities in the section. Although they normally do not work on activities in another section, they may be temporarily transferred on special assignments.

As an organization device, the grouping of related functions offers these advantages:

1. Since department engineers specialize within a narrow field, they rapidly develop high technical proficiency.

2. By limiting the range of its engineers' activity, the department can operate successfully with personnel of more limited experience.

3. Engineers can be easily assigned to tasks that best suit their talents and interests.

4. Line supervisors assigned to the department for special training before advancement can learn much about industrial engineering in a short time.

ORGANIZATION PARALLELING THAT OF PRODUCTION DIVISION

The other common pattern for the internal organization of the Industrial Engineering Department is to parallel the organization of the Production Division. In a plant that has, for example, a heavy machine department, a light machine department, and an assembly department, Industrial Engineering may be organized in sections to provide all (or almost all) the industrial engineering services to each. The engineers in each section work with flexibility on all the problems of their allied production department. They are also transferred much more freely between sections than are their counterparts in departments organized by a grouping of related functions.

It is interesting to note that all companies with this type of organization invariably had one "floating" section that was not tied to any specific production department. It was ordinarily concerned with such activities as supervisory training, job evaluation, merit rating, and so forth. The engineers working on those activities did so in all production departments served by the Industrial Engineering Department.

Several advantages are ascribed to an organization pattern along Production Division lines:

1. This arrangement ensures that the highest priority problem in each production department gets earliest attention. Rarely are all engineers in a section engaged on a special project.

2. An easy and friendly working relationship usually develops earlier between production department supervisors and the industrial engineers.

3. The supervisors gain a good perspective on the production department's operations.

4. This form of organization provides excellent specialized training for individuals being groomed as line supervisors of the department served.

5. When men are transferred between sections of the Industrial Engineering Department, they bring a fresh viewpoint that facilitates problem solving.

6. Men working on all aspects of a department's problems receive very broad training and a good picture of how industrial engineering services complete and complement the production department. This enlarges their growth opportunities and promotes a better Industrial Engineering Department.

ORGANIZATION ON A PROJECT BASIS

Regardless of how the Industrial Engineering Department as such is organized, all companies assemble special teams from time to time to conduct certain projects. Some companies regularly maintain a "floating" section for just that purpose. In most cases, however, the special project team includes engineers temporarily recruited from the various sections of the Industrial Engineering Department. Project teams may be formed for an assignment in the Production Division - for example, to overhaul the wage incentive plan - or for special work in another division not ordinarily served by the department.

FACTORS GOVERNING CHOICE OF ORGANIZATION PATTERN

Why a company chooses one form of internal organization in preference to the other is due to some of these considerations: (1) complexity of production operations, (2) size of plant and production departments, (3) single- or multiple-plant operations, (4) scope of services provided by the Industrial Engineering Department, and (5) types of services provided (e.g., wide-coverage wage incentive programs).

Multi-plant companies with a home office industrial engineering group organized on a functional basis (i.e., by a grouping of related activities) tended to organize the Industrial Engineering Departments of the plants in a similar way. This was especially apparent where the plants produced different products, the reason being that it enabled headquarters to coordinate the plants effectively despite the dissimilarities in production. In multi-plant companies with highly autonomous plants, the pattern was the reverse. There Industrial Engineering was organized to parallel the departmental organization of the Production Division.

Where the Industrial Engineering Department is the major service group in the company and regularly works in other divisions besides Production, it is usually organized by a grouping of related functions. In some instances, however, companies adhere to no specific organization plan but use Industrial Engineering in the ways they feel make the most productive use of present department members.

NATURE AND EXTENT OF INDUSTRIAL ENGINEERING SERVICES

Whether the department is organized formally or informally, it will be expected to perform many services throughout the company. The extent of those services will depend largely on how management wishes to use Industrial Engineering. Many services, however, are an accepted part of the industrial engineering function and, as

such, are germane to the present discussion. Part of the job of organizing any department is to define its duties and responsibilities, outline its personnel requirements, and suggest its policies for internal administration. Personnel requirements and departmental administration are discussed a little later. The various services and responsibilities of the department are treated here.

CONTINUING SERVICES TO PRODUCTION DEPARTMENTS

Virtually all Industrial Engineering Departments provide continuing services to departments of the Production Division. The services may be few or many and normally include such functions as time studies, methods studies, and development of wage incentive programs. The Industrial Engineering Department is ordinarily held fully responsible for the applicability and accuracy of the programs developed and recommended.

INTERMITTENT SERVICES TO PRODUCTION AND OTHER DIVISIONS

Besides its regular, continuing services to departments of the Production Division, Industrial Engineering may be asked from time to time to take on other work for Production or for other divisions. It may, for example, be asked to check the fabrication and assembly problems encountered in new product designs; to participate in the drawing up of labor contract proposals and in contract negotiations; to program the taking of a physical inventory.

On assignments of these kinds the Industrial Engineering Department customarily acts only as an expert advisor. Responsibility for the actions taken rests jointly with the department requesting assistance and the Industrial Engineering Department.

SPECIAL SERVICES (NORMALLY ONE-TIME)

Often companies are faced with problems that will probably never recur, such as the search for a new plant location or the possible acquisition of another company. In some cases the Industrial Engineering Department is assigned to head such projects; in others it may participate in a less important role.

The performance reputation of the department will undoubtedly have an important influence on the scope of its responsibilities in these studies. Whether it or some other participant is put in charge of the project is immaterial; what matters is that whoever is in charge should define the role and responsibility of every participant. Industrial Engineering can then execute its task and assume its defined share of the total task.

SERVICES IN AREAS NOT DIRECTLY RELATED TO THE PRODUCTION DIVISION

The specialized background, training, and experience of the Industrial Engineering Department and its role as a service group with available manpower frequently lead to its being called in on problems foreign to production activities. Examples of this type of service include a review of Sales Department order-handling procedures, an appraisal of Accounting Department bookkeeping machines, studies of office mail and telephone services, etc.

On problems like these, Industrial Engineering should be held responsible for the studies it makes, the conclusions it reaches, and the recommendations it offers. If the department head feels that his group is not well qualified to undertake the assignment, he should make this known to his superior in advance. When the project is completed, he should explain in his report any departmental limitations that have a bearing on the conclusions and recommendations presented.

V. INDUSTRIAL ENGINEERING PERSONNEL

The same principles of personnel administration that apply to other line and functional departments apply likewise to Industrial Engineering. Each of us is undoubtedly familiar with them. What one may ignore are the special personnel considerations that set Industrial Engineering a little apart from the general run of departments. The major distinctions are:

INDUSTRIAL ENGINEERING AS A CAREER

Often the Industrial Engineering Department is staffed largely by recent college graduates whose major qualification is educational background. These men may lack the stature and maturity to influence action. In "selling" incentive piece rates to workers, in gaining the confidence of line supervisors, and in persuading executives to act, maturity and firsthand experience are beneficial. It therefore appears desirable that the well-staffed department have enough senior engineers to balance the younger group. That presupposes the existence of tangible career opportunities, for senior men are attracted and held only in that way.

The Industrial Engineering Department does offer career opportunities in these respects:

1. Young engineers entering the department become well schooled not only in industrial engineering techniques but also in the line jobs they serve. In time, should they elect to make a career of industrial engineering, they can specialize in one field -- say methods work or wage administration -- and eventually

be recognized as an authority in the company. Should their natural bents lead them toward production work, there are often opportunities to transfer into line jobs, where there are further opportunities for advancement.

2. The department is an excellent training ground for operating supervisors seeking to broaden their experience so that they may qualify for promotion to more important managerial positions. It also offers opportunity to men from other departments who would like to specialize in one phase of industrial engineering.

3. A challenging idea has been experimented with where a line supervisor was transferred into the Industrial Engineering Department to spend his last years before retirement. This transfer was made to give the young industrial engineers a fine and experienced guide and colleague; it should also lessen many of the early anxieties of the successor in the operating department, for the new supervisor could freely consult him on departmental administrative problems.

QUALIFICATIONS TO BE SOUGHT IN THE STAFF

The criteria for selection of industrial engineers will depend on the scope of the department's activities, the make-up of the present staff, and the department's program for developing personnel. In general these qualifications should be sought:

1. Knowledge requirements

   - Working understanding of production and engineering problems, or
   - College training or equivalent practical experience in engineering

2. Personal qualifications

   - Above-average intelligence
   - Analytical mind
   - Temperament and personality to move people to act even though no authority to order action exists
   - Ability to work with other department members, workers, line supervisors, management, and union officials and gain their confidence
   - Ability to present ideas clearly.

In addition to these qualifications, candidates should be judged on their fitness for the role industrial engineering plays in business today. An investment in superior men usually pays off in the performance of superior work.

TRAINING

An Industrial Engineering Department is almost invariably considered a wonderful training ground, but too often nothing is done to ensure that the training is complete and effective. This is as shortsighted as turning a man loose in a research laboratory and hoping that, with all the experiments going on, he will learn a lot. The experience may be interesting but not productive.

Training in industrial engineering should be formalized. The first obvious step is a good orientation program in which the new man learns what the department's mission is. If he is not familiar with operations in the departments Industrial Engineering serves, he needs that orientation too. Then he must get specific training in the following areas:

1. Methods and procedures used by the Industrial Engineering Department.

2. The formal and informal organization structures of the company, the Production Division, and the Industrial Engineering Department.

3. The technique of operating in a service atmosphere and dealing with workers, supervisors, management, and union officials.

4. Pertinent technical phases of production operations.

5. Company policies on time study, wage administration, areas of participation by the union, craft observance, etc.

If he is a new employee, he should also have the regular company indoctrination.

RECOGNITION

Unless the subject receives proper attention, the Industrial Engineering Department may, in crediting operating departments for taking action, fail to obtain recognition for its own contributions and accomplishments. Too often the recognition it does receive is not reflected on the responsible department member.

Recognition of both the department's and the individual's contributions is important. First, it stimulates further good work.

Second, it builds the reputation of the department and thus encourages operating departments to make wider use of its services.

To ensure that its contributions and accomplishments are properly recognized, the Industrial Engineering Department might take these steps:

1. Prepare annual programs of work and anticipated attainments in dollar savings, just as a line department does; prepare period progress control reports listing accomplishments to date.

2. Promote internal recognition of accomplishment and outside-the-company publicity on work done and, where applicable, give the names of the department members making major contributions. Technical society papers and magazine articles are excellent publicity outlets. Internal recognition can be gained by reports which point up individual and group accomplishments, assignment to greater responsibilities or more complex problems and pay increased.

PROMOTION AVENUES

How industrial engineering work qualifies an engineer for promotion to a position of greater authority and responsibility was touched on in the section describing industrial engineering as a career. A few additional observations might be made here.

The career of each department member should not be overly preplanned. Even more important, opportunities for promotion to important production posts should not be denied to members of the department on the grounds that they are indispensable in their present duties. One reason many men are attracted to industrial engineering work is that it provides training for line and staff positions within and outside the Production Division. Within the Production Division are the possibilities of supervisory jobs in production - either foreman, assistant superintendent, or higher, depending on the individual's capabilities. Production Division staff jobs to which the engineer may aspire include manager of production control, supervisor of quality control, assistant to plant manager. Outside the Production Division, men with industrial engineering experience have successfully become procedures coordinators, members of industrial relations departments, sales engineers specializing in product application, etc.

These promotion avenues are open to the industrial engineer for two reasons:

1. He is familiar with a wide range of company activities.

2. His approach to problem solving - the scientific approach - can be applied to many situations in the company.

VI. DEPARTMENTAL ADMINISTRATION

Successful administration of a functional department such as Industrial Engineering is perhaps more difficult to achieve than that of a line department. One reason is that it is more difficult to develop and administer standards of performance and to measure attainment. That inherent difficulty may, however, be turned to the advantage of the department. Since department members receive less direction and control than operating personnel, they must be self-starters in order for work to get done. Their pride in doing a job well and quickly is a great asset to successful administration.

Other factors that contribute to successful administration are discussed below.

ESTABLISHING PRIORITIES FOR PROJECTS

It is beyond the scope of this paper to recommend specific procedures for determining what projects the Industrial Engineering Department should and should not undertake. Every project selected, however, should be assigned a priority. Here are some points Industrial Engineering should consider in scheduling its work load:

1. Potential value of solution. Each project should be appraised to determine how the problem might be solved and how that solution would benefit the company. This review may lower the priority of the assignment or even eliminate some work.

2. Effects of delay. Having projected the potential value of a solution, the industrial engineer can gauge the adverse effects of not taking immediate action. This will further assist him in ranking projects.

3. Probable duration of activity. Before deciding whether delay will lessen the value of a solution, the engineer should look closely into the activity to be studied to see whether it is likely to be superseded or reduced. If external factors are apt to cancel or diminish the benefits he had foreseen, he should take them into account in timing his assignment.

4. Wishes of line supervisor. Although the criteria applied may point to a specific priority schedule, the Industrial Engineering Department should check that schedule with the Production Division. Sometimes a line supervisor may, for administrative reasons, wish to rearrange the sequence of projects. His reasoning should be accepted unless there is a compelling argument against it.

5. Conflicts with previously scheduled projects. Now and then every Industrial Engineering Department has a run of projects that demand top priority. Previously scheduled studies, some of them perhaps on the docket for a long time, are consequently pushed back and the priority list is revised. Such action is admittedly justified in an emergency, but it should always be carefully considered, for it can easily cause ill will and misunderstanding.

It seems, by the way, that resolving schedule conflicts is usually more difficult for the Industrial Engineering Department that is internally organized by a grouping of related functions than for the one organized in sections to serve specific departments. In the first case a section of Industrial Engineering is a jack-of-one-trade to all the departments. Its working relationships are not so close or its lines of communication so direct as those of the department organized to parallel the Production Division. The latter type of department can usually explain priority changes with no trouble since its work is confined to only one area.

Regardless of the problems created by schedule changes, all Industrial Engineering Departments, however organized internally, have a responsibility to themselves and to the company to examine schedule conflicts objectively and to resolve them in a way that will benefit the company most.

6. Training opportunities. Ideally, the young industrial engineer should cut his teeth on a simple project and gradually work up to the more complicated ones. Priority lists, however, seldom progress so nicely from the simple to the complex. Projects usually must be undertaken in the order of their urgency, with little thought about their complications. Sometimes, however, all other things being equal, the Chief Industrial Engineer can and should schedule or re-schedule work to take advantage of the inherent training opportunities.

PROGRAMMING THE WORK

When priorities have been assigned, it is the job of the Chief Industrial Engineer and the section heads to program the work. This entails five steps:

1. Ensuring that manpower is available for continuing services. Department and section heads should review the priority list to determine whether any conflicts are apt to arise. They should also review the schedule of individual engineers. Despite their attractiveness, special projects should not be allowed to interfere with continuing services without approval by the head of the Production Division.

2. Subdividing work. Subdividing the work expedites it, as for engineers' skills or training needs can be matched with work requirements. Subdivision also brings in more points of view and greater flexibility. It is usually wise to delegate routine tasks to workers with clerical skills so that the engineers can devote the greater part of their time to the technical aspects of the study.

3. Establishing time schedules. Realistic deadlines for each step of the project are an important part of programming and of every other phase of a study.

4. Scheduling outside participation. If the project will require the assistance of persons outside the Industrial Engineering Department, that should be included in the programming of work. The people concerned should be notified well in advance and their assignment confirmed by their department heads so that no conflicting demands will be made on their time.

5. Briefing all participants. A most important part of programming is to explain the project to each man on the job. He should understand what the objectives are, what his assignment is, and how it ties in with the whole so that his contributions can be complete. Often he will offer excellent suggestions on work outside his own area of responsibility which contribute to the progress and success of the undertaking.

REVIEWING THE PROGRESS OF THE PROJECT

The best run companies have found that each project should have its check points selected in advance and that progress should be reviewed on a preplanned schedule. A project control system should also be prepared so that the Chief Industrial Engineer can tell at a glance how things stand.

Check points during the project. Almost any measure can be used as check points for a project; a time period, a number of dollars spent, a number of hours recorded, or a combination of these.

Project control. The project control system should provide progress reports to be recorded against the schedule. It should be similar to that used for production control in the factory. A Gantt chart or some other comparable control system which shows job status and estimates of time to complete further stages can be used. With such a system, the Chief Industrial Engineer and section heads can tell at a glance which projects are behind schedule. That in turn will permit them to "control by exception" - i.e., ignore on-schedule projects between progress reviews and concentrate on those that lag.

PRESENTING FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

If it wishes to make the best use of its time and gain the best reception of its recommendations, the Industrial Engineering Department will give careful thought to the point of view of the line department supervisors served. This is not to imply that it must form conclusions and present recommendations that are unsound; rather it is to point up the need for using diplomacy and common sense in presenting recommendations.

Here are some suggestions to bear in mind:

1. Determine the facts necessary to gain conviction. In persuading an executive that recommendations are sound, the Industrial Engineering Department should limit the facts presented in support of a recommendation to those that it believes will soundly influence the executive. It is idle to recite all the facts when only certain ones are controlling.

2. Anticipate objections and be prepared to overcome them. Presentations should be planned to convince specific individuals. In that way the Industrial Engineering Department can develop the presentation so that it removes any doubts the department believes the executive may have. In addition, the presentation can, where desirable, provide an "escape hatch" for the executive should he feel remiss about not having taken the recommended action earlier on his own initiative.

3. Select proper method of reporting. The Industrial Engineering Department usually knows in advance to whom the initial presentation will be made. If it has reason to believe the material will be put to other uses, it should try to select a reporting method that will do for all. Often it is possible, with sound preplanning, to use photostatic copies of the same material on an easel, in a bound report, and also as the basis for developing the installation program to be followed. Where there is doubt, the extra time and effort should be expended in preparing several presentations rather than a single omnibus one with its inherent limitations.

4. Maintain good records. Following sound persuasion techniques may be dangerous if the engineer has not maintained good records. Facts that may not have been necessary to a persuasive presentation may be questioned when the recommendations are being put into effect. Unless the engineer has recorded them in his working papers, he may be at a loss to justify his position.

Besides the "protection" good working papers give, they have important value as a reference library. They frequently are helpful on later studies. No project should be considered

finished until an action program is under way and the records and working papers sorted, coded, and properly filed.

VII. GETTING ACTION ON RECOMMENDED PROGRAMS

Since Industrial Engineering is a service department without line authority, it often has difficulty in getting people to act on its recommended programs. This can be minimized by the manner in which the study is made - i.e., whether or not the department "sells" as it goes along. It can also be minimized if the recommendation is in the form of an action program that makes it easy for management to act. Other steps the Industrial Engineering Department can take to induce action include:

1. Emphasize benefits to entire company. The broader the range of significant benefits, the more likely that action will result. First, more members of management will be interested in achieving the benefits; second, the action cannot die through the inertia of one executive.

2. Point up compensating benefits to individuals. If a recommended action program will relieve executives of problems, the desirability of action will be enhanced. If the recommendations reduce the number of workers reporting to an executive or otherwise lessen his prestige or authority, the attendant benefits must be strongly emphasized to get him to act.

3. Spell out the action program. The action program should describe each step and designate each participant's responsibility and the date projected for completion of his assignment. Such a program will make it easy for management to take action.

4. Provide progress check points in the installation plan for use by line supervision. The installation plan should have a procedure for controlling the progress of the installation similar to that recommended for projects within the Industrial Engineering Department. Where practicable, a member of line operating management, rather than a member of the Industrial Engineering Department, should follow up the installation program.

CONCLUSION

This paper has intended to cover the broad subject of Organizing for Industrial Engineering. It puts forth my contention that the effectiveness with which an Industrial Engineering Department operates largely depends on how well the following factors are understood and weighed. The Industrial Engineering Department

must be considered in terms of its:

1. Role in business today.
2. Working relationships with other departments.
3. Place in company plan of organization.
4. Departmental plan of organization.
5. Personnel.
6. Administration.
7. Getting action on recommended programs.

Where these factors are properly related, a company can expect continuing improvements in controls over production costs and steady reductions in actual production costs.

THE DEVELOPING RELATIONSHIP BETWEEN COLLECTIVE BARGAINING AND INDUSTRIAL ENGINEERING SINCE THE CLOSE OF WORLD WAR II

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The special industrial engineering techniques of interest to the trade unionist cover the whole gamut of management. Items remote from the employer-employee relationships like sales management, production scheduling and routing have their impact on the employer-employee relationship. They determine the effectiveness of the business, the profitability of the enterprise and the ability of the employer to pay the workers not only a living, but a prosperous wage.

However, I wish to confine my attention to those particular techniques that impinge most directly on the day-to-day collective bargaining activity in which both engineer and shop steward find themselves involved. These functions cover the area of job evaluation, production rate setting by time study, and the administration of wage incentive payment plans. These techniques were found particularly useful by the trade unionist during World War II.

The evolving relationship between the industrial engineers and the trade unionists during this period, can best be understood against the background of the special problems that the labor movement faced during the war.

The labor movement had not had an opportunity to really digest its newly found members immediately prior to World War II. The great organizing campaigns that began with the sit downs in rubber and automobile in 1937 had brought thousands upon thousands of workers into the trade union fold. The normal maturing process during the course of which local leadership would be trained to handle the day-to-day tasks of the shop stewards and shop committees had not had an opportunity to operate.

Management for its part had not yet really reconciled itself to the permanent establishment of a trade union movement, as a normative part of our industrial culture. A newly organized Liberty League, made up of management's leading legal luminaries, had gratuitously usurped the function of the Supreme Court of the United States and declared the Wagner Labor Act unconstitutional in the mid-1930's. The result was that between the passage of the Act and the declaration of its constitutionality in 1937, management had felt free to behave towards unions in very much the same

pattern that they had pursued in the 1920's; or at least, if they had to compromise, felt that this was but a temporary strategem, pending a final showdown when a return to the country's political climate of 1920 would make such an undertaking feasible.

The declaration by the Supreme Court that the Wagner Act was constitutional came upon management like a thunderclap in the middle of the night. It was not prepared to meet this obligation emotionally or operationally. Management's churlish self-righteousness had elicited a corresponding antagonistic attitude from the trade unionist and each side had squared off in its corner. An uneasy truce only kept them from coming to blows. The constitutional verification of the Labor Act started a normal maturing process that did not receive much publicity. This maturing process was frustrated when the United States found itself embroiled in the second World War.

Labor was called upon for a no-strike pledge and in return the government, through its various commissions like the War Labor Board, provided what amounted to tribunals that imposed compulsory arbitration of disputes on both sides.

The inflationary pressures that began to build up under the stress of the industrial war effort led the government to impose a ceiling on wage increases. The labor movement felt completely thwarted. They reasoned, "It's obvious that it is difficult to strike successfully when there are nine million unemployed such as there were in 1939 in order to get any decent wage increase. And now the government tells you that you can't strike when there is a labor shortage.

Strategically, we are always in the position of "heads they win and tails we lose." This was the prevailing temper.

It was the job of the War Labor Board to administer the anti-inflation program through the government in such a way that wage adjustments could be carried on without increasing the labor costs of the products being manufactured. Suddenly the engineers and the trade unionists found themselves in an uneasy alliance. One of the rules promulgated by the War Labor Board was that a restricted amount of money could be added to the payroll to correct inequities in the wage structure. The trade unionist turned to the job evaluation specialist to make the inequities look big. Management turned to the job evaluation specialist to make the inequities look small.

The War Labor Board caught in between, developed its own formal job evaluation procedures in order to rationalize its decisions between the contending experts. Wage incentive payment plans and the required procedures for setting production standards underpinning

the plans was suddenly adopted by unions who had long opposed any wage payments by results. In many cases these wage incentive payment plans led to increases in production for which workers were correspondingly rewarded.

In other cases, they were favorite devices for the avoidance of the War Labor Board restrictive regulations. It was a relatively easy matter to enforce regulations governing straight time payments to workers. All that was needed was inspection of the payroll books. The administration however, of complicated piece rates was completely beyond the capacity of the War Labor Board. The dynamic behavior of American industry meant that old methods of making old products rapidly became obsolete; new methods were being devised for making new products, new ways were being developed for making old products, and finally new methods were perfected for making new products. This lent American industry its élan. It led Stalin to drink a toast to American productivity, while all the future red investigators naively were flattered and cheered. But it meant that the administrative job of the War Labor Board was hopeless. Who was competent to check whether or not every production standard and every time study was set to yield the legal earning opportunity specified by the little steel formula?

The engineers took their consulting fees, the employers took their prices, the workers took their wages and old feuds were buried and the basis for new conflicts were laid. Statement after statement, directive after directive, memorandum after memorandum issued from the War Labor Board in a futile attempt to cover with rhetoric what could not be handled operationally. Everybody was happy except the long term economist. Everybody was busy living in the short run. Then the war ended.

The employers were frightened by their complete confusion and their inability to see the new market. Many of them compensated for their fears by wild talk about how they were going to teach labor its place.

At that time I remember we had under contract a small factory of the General Electric Corporation in Lowell, Mass. I found myself negotiating directly with the vice president in charge of industrial relations for the corporation. I remember the alarm he expressed at the locker room talk of his colleagues where they evidently indulged their aggressions by boasting what they were going to do those labor s.o.b.'s. This was the emotional climate governing labor relations at that time.

The labor movement was frightened. It remembered that in 1919 and 1920 the great organizational gains of World War I had been completely liquidated, by a post-war union busting campaign.

The N.A.M. had promulgated the American Plan and within a short time organized labor ranks had been decimated. Woodrow Wilson had convened an industrial relations conference in 1919. It was made up of the leading members of the labor movement and the leading management members of the country. The tone of the conference was set by Elbert H. Garry, President of U.S. Steel. The conference recognized the right of every worker to join a union, and the right of every employer to either deal with a union or not, as he chose. Most of management chose not to deal with a union. To be sure, there were isolated islands of union-management cooperation experiments here and there, like the Baltimore and Ohio plan. But by and large, the policy of American management that counted was to fight actively the trade union movement. The question in the minds of the trade unionists at the end of World War II was "would history repeat itself?"

On the other hand, the engineers provided a breach in the mid-1920's in the solid front of management thinking. The scientific management movement voiced a refreshing departure from the prejudices of top American management. The industrial engineers under the leadership of men like Harlow Persons and Morris L. Cooke had worked successfully with the trade unionists during the war. Immediately after the war they were prominently identified with outstanding union management experiments like the joint application of time study to setting incentive wage rate standards in the Cleveland Ladies Garment market.

This experiment was conducted under the leadership of Morris L. Cooke, an old associate of Frederick Taylor who had become a close friend of Samuel Gompers during World War I.

The Taylor Society provided a forum for the dissident thinkers among management including men like Otto Beyer who was responsible for the administration of the B. & O. Plan. They reprinted in their Journal the classic paper of R. G. Valentine, "The Relationship Between Efficiency and Consent." This was the first paper to lay down a philosophy upon which both management and labor could cooperate within a scientific management frame of reference. This was the historical experience which labor, management and the engineers brought to 1946. The engineers had their dissident left wing tradition upon which to draw. The employers had their fighting slogans to which they could return and the insecure labor movement had its bitter memories with which to project the future.

President Truman, like his predecessor Woodrow Wilson, also called a labor management conference. A key subcommittee of the conference, made up of equal number of representatives from management and labor, was the Management's Right to Manage Committee. The committee was unable to agree.

The management members addressed a letter to the conference, extracts from which follow:

"Labor members of the committee on Management's Right to Manage have been unwilling to agree on any listing of specific management functions . . . . if labor disputes are to be mizimized by the genuine acceptance by organized labor of the functions and responsibilities of management to direct the operation of an enterprise, labor must agree that certain specific functions and responsibilities of management are not subject to collective bargaining."

The committee then went on to list some of the duties which they felt were outside the jurisdiction of collective bargaining:

"The location of the business, including the establishment of new units and the relocation or closing of old units. . . . . .

". . . The determination of job content; the determination of the size of the work force; the allocation and assignment of work to workers."

The labor group on the other hand pointed out that:

"The extensive exploratory discussions of the committee have brought forth the wide variety of traditions, customs and practices that have grown out of relationships between unions and management in various industries over a long period of time.

"It would be extremely unwise to build a fence around the rights and responsibilities of management on the one hand and unions on the other. The experience of many years shows that with the growth of mutual understanding the responsibilities of one of the parties today may well become the joint responsibility of both parties tomorrow."

Labor was in short accusing management of committing the logical fallacy of "false concreteness", a favorite fallacy of the legal-minded who must fit all living phenomena into a system of verbal categories. It was in this environment that the labor movement philosophy of industrial engineering developed.

In the midst of this labor-management conference in Dec. 1945, the United Auto Workers, under the leadership of then Vice President Walter Reuther, called a strike against General Motors Corp. that was to last 118 days. Reuther demanded that the corporation increase wages 30% and offered to prove, if management would open its books, that the corporation could afford to pay this increase, reduce the price of a Chevrolet $50, and still make the largest profits in its history.

The anger of the company was more directed at the Reuther proposal that they open their books and the invasion of the area of price policy, than by any of the economic demands. They accused him of using the union to promote a socialist ideology, and insisted that price policy and ability to pay were outside the scope of collective bargaining.

Among the counter demands served by General Motors Corporation upon the union was the extension of the work week to 45 hours per week at straight time, and the institution of wage incentive payment plans all over the General Motors empire.

The attitudes within the U.A.W. on wage incentive payment plans during the war had been a matter of dispute. One faction called for their promotion in order to cope with the ceiling imposed by the little steel formula. The other group remembering the bitter experience of the automobile workers during the '30's when piece rates were cut unilaterally, wanted no part of these plans.

The demand of the corporation that the plans be spread solidified the entire union behind the position of opposition to the plans.

While the auto workers were still on strike, Phil Murray led the steel workers out of the mills in January 1946. Both strikes were settled finally with the aid of government fact finding boards. The wage settlement was 18½ cents per hour. This became the first step in a system of Post War pattern wage settlements.

Phil Murray refused to go along with Reuther's intervention in the price policy of the corporation and the entire matter was dropped by the General Motors workers as well.

On April 1, 1946, John L. Lewis' demand for a royalty payment on each ton of coal to finance a welfare fund led to such employer opposition that the government was forced to seize the mines. They were operated by Julius Krug, Secretary of the Interior, and a welfare fund was negotiated by John L. Lewis and the government. Lewis still remained unsatisfied and called a strike against the United States Government. On Dec. 3, 1946, Judge Allan T. Goldsborough found the United Mine Workers guilty of violating an injunction against the U.S. government and levied a heavy fine against the union generally and against Mr. Lewis personally.

Finally on May 23 the railway train men and engineers tied up all the railroads of the country because they would not accept the findings of a railway settlement board to which all the other railway unions agreed. President Truman appeared before a joint session of Congress and called for legislation to draft the railway workers into the armed forces. While he was calling for

legislation, the two railway unions yielded to his demand to end the strike, and the legislation he recommended failed largely because of the opposition of men like Senator Taft of Ohio. During 1946 a total of 4,006,000 workers were involved in strikes and there was a total loss of 116,000,000 man days of work.

In the midst of all of this turmoil, management-labor disputes were constantly on page one of the nation's newspapers. Public frustration was rapidly building itself up into a hysterical wave that was to result in the passage of the Taft-Hartley Act.

Significantly, however, simultaneously with all this public turmoil, a maturing process was at work of much more significance but of much less publicity value than the strike news. Very quietly the wild cat strike leader of yesterday was learning how to sit down and work through a grievance with a superintendent. The tough manager was learning how to adjust to the thinking of the trade unionist. It is interesting to speculate whether or not the Taft-Hartley Act would ever have been passed if it had managed to escape passage in the 80th Congress.

The reason we have good labor relations in the United States today is that the pace-setters of American management have declined to take advantage of many of the provisions of the Act that would result in union busting. It's important that in reviewing this piece of history that we keep our dates clearly in mind because they provide the present day industrial relations environment within which we are able to examine the interaction between the industrial engineers and the leadership of the American Labor movement.

On Jan. 5, 1947, Charles E. Wilson, president of General Motors Corp. was testifying before the Senate Committee on labor and public welfare. He stated "I will not have a closed shop. . . I am never going to sign one. When it gets around to that, it will make a farmer out of me."

By June 12, 1947, the Taft-Hartley Act was passed over the veto of President Truman. However, by May 29, 1948, a pioneering five-year agreement between the General Motors Corp. and the United Auto Workers was negotiated. This called for a 180° turn in the policy of the General Motors Corp. in dealing with the auto workers' union. A new improvement factor was built into the collective agreement that made the workers automatic participants in the increasing productivity of the corporation. Subsequent negotiations following this Act converted the clauses on maintenance of membership to complete union shops. General Motors set the pattern and the other leading industrialists in the country followed. It might be added parenthetically that the adoption of the union shop by the Ford Motor Company antedated the General Motors adoption of this policy.

However, it was the acknowledgment of the union shop as a legitimate union objective by General Motors that set the pattern for the other major sections of American industry to follow down the line. Charlie Wilson was accused of class treachery by many of his fellow managerial ideologists. Unreconstructed class-struggle trade unionists warned their more "gullible" associates against this streamlined bribery. I imagine at times Mr. Wilson himself was uneasy because of his lack of consistency, but this very inconsistency is the greatest tribute which we can pay to him. Here was a man who was able to learn from his experience and given the choice in finding the pragmatic solution to a problem he faced and loyalty to an obsolete ideology, he chose the courage of his inconsistency. I feel there is more to the key of American productivity in this type of managerial behavior than in all the learned treatises on this subject that find their way into print.

It is no wonder that Fred Hartley, who was co-author of the Taft-Hartley Act, complained bitterly later that employers were surrendering to the union bosses. They were not making use of the tools he made available to smash the union. He had declined to run for re-election to Congress and set himself up as an expert consultant on how management could make use of the law to thwart the unions and discovered that the purchasers of his services were strictly third and fourth string prestige carriers in American industry.

It was during this period that any labor representative addressing a management gathering was faced with the question, "What are you going to do about wild cats?" We would patiently reply that they would disappear in the natural course of the maturing process. Today they are no problem. American unions feel secure in their relationships with major American industrialists, with the exception of the right wing lunatic fringe of American industry.

The Taft-Hartley Act has primarily been useful for marginal industrialists who have fought off organization of their workers in the Southern sectors of textile and woodwork. John L. Lewis, at whom it was aimed, has remained unscathed. This story has provided us with a background against which we can now examine what has happened in the various sectors of industrial engineering, vis a vis the labor movement. The history of the relationship between the engineers and the labor movement since World War II can be examined on two different levels.

The first level can best be illustrated in terms of a few cases that have highlighted the relationships between individual trade unions and companies in the course of negotiations, arbitrations and court cases.

The second level is concerned with the official relationships as they have played themselves out in the activities of the groups who speak on behalf of labor and the engineers. In the case of the labor movement, it would be both the American Federation of Labor and the Congress of Industrial Organization. In the case of the engineers, the Society for the Advancement of Management up until a few years ago, when the AIIE was created.

The status of job evaluation as a subject for collective bargaining has been long established. The latest decision in a number of cases that have been heard by the NLRB was handed down August 16, 1955. It involved a case between the Forge and Machine Workers Industrial Union and the Taylor Forge Pipe Works. The trial examiner found that the employer had refused to bargain with the union by refusing during collective bargaining negotiations to furnish the union with job evaluation point schedules. Although this decision clearly spells out the nature of the union's equity in this procedure, the principle question remains to what extent do unions find job evaluation a useful collective bargaining tool? The points of view that were current in the labor movement at the end of World War II in 1946 were clearly brought out in a conference of trade union technicians held under the auspices of the University of Chicago. There is little point in reviewing again the varied points of view that came to light at that time. Some of us may recall that Sol Barkin of the Textile Workers Union and myself were engaged in a rather lengthy debate that received widespread publicity at that time about whether or not job evaluation could be used as a collective bargaining tool. This debate was pretty well settled by the steel workers' adoption of a job evaluation scheme to govern the relationship between itself and the U.S. Steel Corporation. Many problems have arisen under the administration of the plan, but by and large, it remains viable and active.

Another interesting case involves the fate of the Southern California Air Craft industry plan. Some of us may recall that this was the plan that was set up during World War II to govern the classification of jobs in the fast growing aircraft industry.

Clark Kerr and Lloyd Fisher described back in 1950 in detail the problems that arose under the administration of this plan. They stated "The most difficult and pervasive problem in the administration of job description and evaluation in the Pacific Coast aircraft industry arose from the frequent conflicts between measures of external and measures of internal equity. The price of a job in the market is one well-established measure of its worth. The SCAI plan established a different measure of its worth. The conflicts between these different standards made for continuous obstacles to the consistent administration of the plan. . ."

It was discovered both in Southern California and in Seattle that the plan overvalued skill in relation to the factors of job disutility, such as job conditions and physical application.

I recently had the good fortune to be called in by the U.A.W to consult with them in preparation for their collective bargaining negotiations with North American Aviation and Douglas Aircraft. The U.A.W. found itself confronted with a problem opposite to that posed by Fisher and Kerr. Their problem was not the disutility of the jobs, but the ceiling that the plan imposed upon skill and educational requirements. The increasing complexities of plane manufacture had led to educational and skill job requirements far in excess of those anticipated in the So. California

industry plan. The company had attempted to contain these skills within the existing plan by decreasing the step increments in points for each additional year of education required. For example: If three years of education called for 30 points, 10 points per year, four years of education would call for 35 points, the fourth year would be valued at 5 points. A high powered brief was prepared to disclose the inequities of the plan and it was found that we might just as well have spared our efforts. The companies dropped the SCAI Plan with a minimum of pressure.

The United Automobile Workers have negotiated a new agreement with the North American Aviation Corp. effective March 19, 1956.

A new Article XVI, Sec. 3, calls for the designation of three members by the Union and three men by the company to investigate and agree upon a new or modified wage plan.

It will be interesting to watch what develops out of the Board's deliberations during the course of the contract.

Just where does this leave job evaluation as a technique in the determination of relative wages within a plant? I would say just about where some of us would have it belong. It is just one factor among others that will determine relative wages within a plant.

Now let's take a look to see what's happened to wage incentive payment plans. The U.A.W., as I mentioned earlier, has always been officially opposed to wage incentive payment plans. Yet it was with great reluctance that the auto workers were forced to abandon a wage incentive payment plan both with the Willys Corporation in Toledo and the Studebaker Corporation. The agreement of December 1, 1954, between the U.A.W. Local #5 and the Studebaker Corp. has appended to it a letter dated August 13, 1954, signed by Paul M. Clark, Studebaker Vice President, abolishing piece work in the Studebaker plant. Along with it went a reduction in earnings opportunity without a corresponding reduction in work pace. The U.A.W. had undertaken a cooperative effort with the Studebaker Corp. to save the financial position of the institution.

Here it was the union that wanted the continuation of the piece work plan and the company was advocating its abolition. Here again is proof that the policy of a union towards any of these techniques is dictated by the pragmatic economic requirements it finds on the job rather than any preconceived ideological position it may take at a convention.

The recent dispute between the Westinghouse Corp. and the International Union of Electrical Workers revolved around the

setting up of production standards for indirect maintenance workers. A position paper of the Union dated November 25, 1955 spells out the Union's position.

The IUE-CIO has maintained that no work standards should be imposed by Westinghouse on its employees unless the job is put on incentive. The Union maintains that to impose work standards without incentives is to create a "third class" citizenship among Westinghouse workers. Dayworkers on standards would have all the disadvantages of dayworkers (in that they would get no incentive pay), and all the disadvantages of incentive workers (in that they would have to work against a standard).

The Company would have a "one-way street" on this. It claims it can discipline or discharge people who do not meet the standard, but would provide no extra pay for those who exceed it.

We maintain that this is not only an unfair and unworkable program, but in fact, it is contrary to the generally accepted best practices in American industry.

The industrial engineering and trade union conference of 1946 to which we have already referred disclosed the currents of thinking within the labor movement about the application of time study to the setting of production standards. The interest labor has in this technique as a collective bargaining tool was clearly established in the arbitration decision following the Ford Motor strike in 1949 over an alleged speedup. The company was told clearly that although the agreement reserved the right to set production standards that this right was not the same as other management's rights. It was not an absolute right. It was a right to initiate as against an absolute right to determine. The final determination that rate setting was a subject for collective bargaining was important in the conflict that was developing between the labor movement and the organized engineers as represented through the Society for the Advancement of Management.

Obviously, if labor had a right to participate in the process of rate setting, it was not going to countenance the imposition of a system of rate setting unsupported by any scientific foundation. What's worse, this code was unilaterally determined by a management society without any labor consultation. I am referring now to the Society for the Advancement of Management rating study. I have elsewhere made what I consider an adequate analysis of the validity of the S.A.M. rating study. On commenting on it at that time, I wrote:

"The rigorous standards we have chosen to measure the report are dictated by the claims made on behalf of the report by the Society. It has been the advertising program of the Society in selling these films that has led us to the harsh demands of rigor and perfection that we have a right to expect from an 'official' Society code.

"It is questionable whether or not the worthwhile purposes of the Society are advanced by an energetic sales promotion program in which advertising techniques are permitted to play hob with the very excellent scholarly reputation the Society has hitherto enjoyed. Raising money through the sales of these films to finance research purposes is a worthy objective.

"However, the most important purpose the Society has hitherto served has been that of a scholar's forum where material presented before the audience was completely open to the criticism of the scientific community. Doctrines presented there either survived or fell depending upon the ability of their proponents to establish and defend the scientific validity of the rationals behind their recommendations.

"A review of the Society's literature fails to disclose the publication of any non-official material critical of the methods or findings of the investigation. Discussions of the film have assumed the appearance of sales promotion efforts rather than serious attempts to evaluate what has been done."

As a result the American Federationist carried a special editorial denouncing the imposition upon workers of such a unilateral study. Walter Reuther, President of the CIO, in a special memo to his officers, denounced the study and warned union officers against accepting any of these bench marks as arbitration guides in disputes over production standards.

Recently an attempt was made by an employer to make the S.A.M. rating films the arbitration criterion between the employers and the Carpenters Union in any production standards dispute which may arise. The Union again refused to go along. There is no doubt, however, in my mind that here and there some local union will be found, ignorant of general union policy, who will be seduced by the surface plausability of these films. They will eventually learn the folly of their commitment.

Our attitude towards the microscopic standard data systems that have become fashionable since the end of World War II has been to observe that if one of these systems is right, all the others have to be wrong. And yet, strangely enough, they all work. They work because they create an atmosphere that leads to the working out of what the logicians would call a self-demonstrating hypothesis.

The worker knows what the engineer expects. He prefers to avoid fights. He tailors his working pace to suit the expected increment earning. The worker is reasonably happy; the engineer delighted, and the employer is pleased! And I don't see any point in upsetting the miasma of confusion which all of them find so appealing.

I would observe that our attitude is that we will do nothing to expel a system from a plant provided it is clearly understood that the system is not the criterion against which we will measure the adequacy of any single rate. We are free to test check the rate against our own technical criteria. We would insist that an arbitrator hearing a rate dispute between ourselves and any advocate of a predetermined micromotion system, agree in advance that the arbitrator would not confine his evaluation to the methodology or principles of the plan. He must be left free to get his information from all sources.

The place of the industrial engineer in arbitration of production standards has arisen in two significant cases. Case #1 was the Ford Motor Co. to which we have already alluded, and Case #2 is the IUE-Westinghouse case which is still in the process of being determined.

The method used in the Ford Motor case was that the union retained its own expert engineer and the firm designated its expert engineer. The two engineers constituted a panel to choose a third lay member who would be able to resolve any dispute that might arise between the experts.

The IUE-Westinghouse agreement called for the designation by both parties of an impartial engineer. At this time, both IUE and Westinghouse remain deadlocked. I much prefer the approach in the Ford dispute. The reason is not too difficult to see. Any engineer who would be chosen by the parties in dispute is devoted to the highest principles of integrity and is by necessity bound by the particular set of procedures in this controversial field to which he has pledged himself in his writings and research. If he remained without any opinions in this highly fluid field of ours, he would likely be a person either without any courage or without any knowledge. I think a much wiser role for the engineer would be to use his advocacy skills on behalf of his clients and in the best tradition of our democracy, let the intelligent layman choose between the experts. Perhaps an illustration from another field will point up what I mean. During World War II a great controversy arose in the synthetic rubber program between the petroleum chemists and the grain alcohol chemists over what procedure would yield the most promising results. Obviously, no chemist who was an expert in this area could be qualified to resolve this dispute. His very training

and interest immunized him against impartiality. Eventually, the problem had to be resolved by a choice between the two contending groups by government lay administrators.

Now where does all this leave us? We have covered job evaluation, wage incentive payment plans, and time study systems. I would summarize by saying that they all constitute a set of limited empirical techniques that are found useful in collective bargaining. The relative stability of collective bargaining in our prestige pace-setting industries has made it possible to develop adequate means of living together within the framework of these systems. We are all safe as long as we are guided by an old adage first contributed to industrial relation by Prof. John R. Commons. His advice to both management and labor was "Use the expert but never surrender to his tyranny." That is about where we stand today.

MATHEMATICAL PROGRAMMING ON A DO-IT-YOURSELF PLAN

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I would like to tell how we got into Mathematical Programming, what some of our thoughts and ideas were, how we got started and what some of our future plans are. It is indeed gratifying to think that our efforts in the direction of Mathematical Programming, particularly since that effort was initiated through the Industrial Engineering Department, may be of some genuine interest and real benefit to you. For that reason, I shall refrain from burdening you with a technical presentation. I would, however, prefer to relate to you my personal experiences and views along with those of the people that I have been working with concerning Mathematical Programming. As such, these should not be construed to reflect universal thinking within our Company since that would be rather difficult, and generally subject to change. Moreover, I would like to dwell a little on some of the workshop training material as I have acquired it, in the hope that I may leave you with some worthwhile thoughts that might possibly assist you in some manner in your own self-starting efforts.

It would appear appropriate at this time to tell you briefly why we felt we had a need to investigate Mathematical Programming and how we proceeded. Needless to say, with increasing labor and material costs every effort, though extremely difficult, had to be made if we were to hold the line in costs. Difficult to the extent that would appear to make conventional practices sometimes inadequate. Consequently, like all Industrial Engineers, we were constantly probing for new ideas, methods or techniques for cost reduction which can be achieved primarily in two ways; namely, by increasing productivity and decreasing operating expenditures. From the constant stream of informative literature that was constantly passing through our hands, we became more and more aware that Mathematical Programming had been finding successful application in a wide variety of business and industry; however, we knew little about it. We suspected that there may have been many other groups who were interested in it; although we, in the Industrial Engineering Department had seen little evidence that it could possibly help us with our immediate problems.

From the limited knowledge of Mathematical Programming that we had acquired on our own, our first thoughts were that our problems were quite different; at least different to the extent that we couldn't see much analogy from our vantage point between them and the applications that we were reading about. Much of the material that we had gathered pointed to the application of theoretical approaches to long range objectives tying Mathematical Programming into the more complex Operations Research techniques. A rather brief survey, however, brought us to the conclusion that our problems weren't so different after all. They were essentially the same as the other fellow's and there was no reason to believe that we couldn't develop and apply Mathematical Programming to our advantages. With this in mind, we began our first real concentrated search for other ways to reduce and control costs. Our immediate thoughts were to isolate Mathematical Programming from the vast field of scientific management, acquire the information we felt was needed and train a series of pilot groups within our own department to further stimulate activity in cost reduction research. At the same time, we were anxious to see just what we could accomplish ourselves.

As Director of Training for the Industrial Engineering Department of the Television and Radio Division of our Company, in the Spring of 1955 I attended a workshop program in Mathematical Programming at the National Institute of Management (formerly Executive Services) in Cleveland, Ohio. It was the only workshop program that we knew of at that time, which we had discovered through an article appearing in an Iron Age publication citing a specific Mathematical Programming application. When I returned, I was both convinced and confident that here was a management tool that could be put to work almost immediately. A brief presentation to the Manager of the Industrial Engineering Department quickly convinced him of its potentialities and that we should proceed as soon as possible with the pilot training that we had been considering. With management approval and endorsement, but with the understanding that we could not disrupt any current activities, our first pilot program got under way within a few weeks.

The material used for our initial program was essentially an almost exact repeat of that which I had received at the workshop. I would like to give you a brief rundown of that material. We felt that it was general enough in nature to provide the stimulus that we were seeking and we didn't feel that we wanted to take the time to sift or arrange the material for any specific requirement. We realized too that we had to first test ourselves to see if we could repeat the material accurately and see if any immediate applications appeared evident. This was not the case with our subsequent programs as each group contributed measurably to adapting the material for the next group. In order that you

may fully understand what you can expect from a workshop program, I would like now to describe the material in general to you, exactly as I received it and as it was passed on. In so doing, I believe you may find some of the comments and opinions of the people who were instructed by us quite interesting and of some value in any training plans you may contemplate. I shall endeavor to inter-relate them for you in the description of the workshop program.

Any program of this nature, introduced to a group of people for the first time, must necessarily begin with a brief history of the subject matter. This usually consists of nothing more than telling your people about Mathematical (Linear) Programming in general; how it grew up in Britain during the last war, the need for it and how it developed. You will find this relatively simple for it is purely a matter of history. I might add here, that the terminology Linear Programming has a tendency to create an enigma in the minds of most shop, office and factory people. It raises the question, "how much mathematical background and knowledge is required to learn and participate in such a program?" This, I believe can be quickly dispelled upon emphasizing that your approach is intended to be one of a practical nature; meaning of course that you are seeking better and quicker methods for problem solution rather than intending to fumble around with cumbersome higher mathematics. Pointing out that a fundamental knowledge of nothing more than high school or first year college algebra is required will do much to dispel such anxieties. Continual reference to Mathematical Programming rather than Linear Programming will also help. In fact, we are still searching for a more appropriate title; but, for want of a title, we are presently referring to it as simply a Training Program.

A brief review of fundamental mathematics was given in the workshop program that I attended. We have found that to be essential. Such a review should include the handling of mathematical terms, constants, coefficients, graph plotting, determinants, simo equations and the rudiments of matrix algebra including mathematical notation. We experienced considerable difficulty in these areas. We are all more or less inclined to drift away from the organized application of mathematics to the solution of the majority of our everyday problems. Because of this, I believe it is usually well to hurdle these obstacles at the beginning for if interest is to be lost it would best be lost then and there. Without interest there can be little genuine desire for learning. And where the desire for learning is lacking, training cannot possibly be effective.

Considerable time was devoted to mathematical notation and problem formation. For as long as we deal with simple problems involving not too many variables, a verbal description is often

adequate. However, if we expect to deal with more complex problems with innumerable inter-related variables, the human mind has a tendency to bog down giving need to a more constant approach. From the numerous workshop case studies, concepts on the establishment of mathematical models can readily be taught. A mathematical model is nothing more than translating a problem into mathematical language for the purpose of solving a business problem. Experience will indicate, I believe, that such concepts make it possible to describe and comprehend the facts of a problem better than any verbal description can hope to. From the mathematical model it is possible to uncover relationships between various aspects of a problem that are not readily apparent, or possibly to explain some of the cause and effect relationships not easily understood. They can also be enlarged step by step to include additional factors stating the problem fully or quantitatively. They may also be used to simulate a set of conditions for a possible aid in decision making. Much can be said about the need for mathematics in a training program. A thorough knowledge of the background of the group to be trained is necessary in order to determine the extent of the training in this area.

Having bridged the gap of mathematical requirements, the workshop program entered right into the subject matter. At this point, a precise definition of Mathematical Programming usually is in order. This is quite a simple matter; for unlike endeavoring to precisely define Operations Research, Mathematical Programming can be defined simply as "group of mathematical procedures for handling a large number of variables each representing a different course of action and selecting the best of these choices." I believe you will find this definition most adequate. If you will recall, I stated earlier that there were some questions in our minds as to whether we actually possessed areas for application. Given in the workshop program are the seven basic requirements for Mathematical Programming which have been developed by the experts, have been thoroughly tested by them in their respective fields of endeavor and have been found to have universal applicability. Since I feel they are all important, I present them to you here as follows:

1. There must be an objective or policy determination.

2. There must be a number of alternate choices or different ways of taking action.

3. There must be some rate of efficiency between these choices.

4. There must be a definable set of upper restrictions or limits; namely, what you cannot exceed.

5. There must be a definable set of lower restrictions or limits; namely, what you must do.

6. There must be an inter-relation or connecting link between these conditions.

7. And finally, there must be a common unit of measure.

With these requirements clearly established, you can reasonably expect to find yourself in a favorable position to begin with the various methods and procedures. The first studies undertaken in the workshop program were those relating to the various Distribution Systems and here the first problem of tailoring quantitatively for any specific requirements becomes evident. It must be remembered that since apparently no concise or consolidated text on Mathematical Programming has appeared to date, all that one can essentially do is to borrow from what has been done in the field. This was summed up very nicely in the workshop program that I attended.

The procedures portion of the program began with the Conventional Distribution System, often referred to as the Transportation or Stepping Stone Method. An article entitled, "The Stepping Stone Method of Explaining Linear Programming Calculations in Transportation Problems" by W. Cooper and A. Charnes will serve as valuable background material. This method is considered rather cumbersome in actual practice but provides the fundamental understanding required for all Distribution Systems. The improved Modi (Modified Distribution) is easier to teach, easier to practice and generally more favorably received by a novice group. Considerable time and treatment was devoted to these methods in the workshop program. I would like to state briefly that these are essentially systems for optimizing a set of conditions dealing with measurable quantities. They can be used for such objectives as maximizing profits, minimizing costs and the like and have found their greatest application in transportation types of problems. Numerous applications have also been made in receiving, shipping, stores and inventory problems. Case studies received from the workshop provide the suitable material basis for developing analogous application. Considerable study was given the Index Method for Machine Allocation or Scheduling; a Simplex type of problem adapted to a Distribution Technique and an excellent example of which is furnished by the workshop. A refinement of this technique entitled the Nora Process is also clearly illustrated. Case studies involving degeneracies, conditions of impossibilities and other forms of peculiarities that may find their way into these systems are studied carefully, since obscure factors that may affect final decision making are generally brought to light. From these workshop examples you will find it relatively simple to seek out your own applications

as we have done. Of course it may be necessary to work with hypothetical situations for a while until one is found that is suitable for application. Problems of selling and installing applications, depending upon their realm and magnitude, can become a source of great difficulties. Since, rarely would any two cases be absolutely identical; it would be rather difficult, if not impossible, to give you a specific example. However, you will find, as we have found, that considerable stimulus for application will arise from these procedures since they are quite simple and easy to handle and capable of furnishing fairly rapid answers.

A comprehensive study of the Simplex, the formalized method of problem solution was made in the workshop. Briefly, this system consists of establishing by means of mathematical notation all of the equations representing the problem in a model form along with its objective in a truly organized fashion. Considerable hardships in formulation are usually experienced by many operating people; because in the absence of a suitable text it is rather difficult to be self-taught by the average man in the shop, the office or the factory. Mathematical minded people as a rule have little difficulty with it; since the problems, once formulated, are solved by a straight-forward procedure. I might add that the technique was developed by Mr. George B. Dantzig, Research Mathematician of the Rand Corporation and I understand has been programmed for computers.

Application of Mathematical Programming to profit, loss, efficiency and utilization studies were given considerable attention as well as problems dealing with Product Mixes and Inventory. Possible application to Market Research, Salary and Promotion Evaluation, Advertising, Testing Procedures and the Game Theory Approach were also demonstrated and discussed. I would like to comment briefly on the latter; Game Theory and Mathematical Programming, for although I can cite no specific practical application, a study entitled "linear Programming in the Solution of Refinery Problem" by Gifford H. Symonds, Chairman of the operations research sub-group of the Esso Standard Oil Company, Linden, N. J., will provide considerable food for thought. I have heard that it is to be published in the near future.

Finally, a short discussion on computing facilities was included to assist in orienting oneself in the present and future requirements for such equipment. We have found that including a major portion of this material will provide a favorable impetus to thought stimulation and at the same time afford a means for adequate practice.

To date, approximately 55 people have received training in our own workshop programs; fashioned in some measure after the material I just described. They include Industrial Engineers, Industrial Engineering Supervisors, Time Study Engineers, Clerks, Test Engineers, Material Control personnel and Labor Cost Engineers. These people were admitted to these programs primarily by appointment arranged to least interfere with their regular activities. A few were taken in either at their own request or that of their respective departments. The amount of training given in these programs varied from a total of 20 hours to approximately 80 hours. To elaborate on the details of the quantitative content of each program would avail little here since that is purely a requirement of specific needs. It might be worthy to mention, however, that experience has indicated the practical limit of the size of these groups to be approximately 15 people. This will invariably yield sufficient time for individual attention and provide for ease of management.

I believe the time has come to outline the objectives of these programs. They may be summed up briefly as follows:

1. To promote a greater interest in the fields of applied mathematics to management problems.

2. To propagate what has been done with Mathematical Programming by telling our people about it and having them do the selling to their associates and contacts.

3. To develop and stimulate immediate application for cost reduction, if possible.

4. To promote and encourage individual as well as group participation and effort.

5. And, ultimately, to prepare operating personnel for integration into Operations Research and Methods Activities.

From some of the earliest indications, it would appear that we shall continue to do this job internally, by selecting the people with the greatest enthusiasm and best background. You see, we feel there are distinct advantages in a Do-it-Yourself Plan. Since they appear to have the earmarks of real significance, I would like to present them here to you:

1. You have people that are completely aware of your own situation and have a better understanding of the company policies.

2. They know the people they have to deal with and, as a result, carry with them some degree of acceptance.

3. They need not necessarily be equipped with the ability to do all the scientific work, but they can consult with and assist each other in formulating and solving problems as well as making proposals to management.

4. Finally, their relationships and associations are relatively permanent; which is a distinct advantage over the consultant approach whose role is by nature generally only a temporary or periodic one as opposed to a continuing one.

In this way, we believe that we can be reasonably assured of developing the nucleus for continued activity.

The question will finally be asked, "What does Mathematical Programming mean to us and what have we accomplished with it?" It should first be remembered that all of our training activities thus far have been on a periodic basis and without the disruption of any existing operations. Admittedly, we don't contend to have trained any experts nor that we are experts ourselves. Neither do we claim any huge successes, since we believe that the applications to date are entirely insignificant of the potentialities of Mathematical Programming. However, we have under consideration several proposals indicating sizable savings which are presently being studied. We do feel that we have made a start and we think it is a good one. We believe too that Mathematical Programming has contributed a great deal toward getting more of our people to think and work with a common tool. From our experience, it would appear that we can expect continual growth and evolution in this area.

It has become apparent to us that it becomes extremely difficult to delineate Mathematical Programming entirely from the various other fields of management. I have recently attended an Operations Research Seminar for the purpose of determining how Mathematical Programming can best be integrated into the broader Operations Research approach. We have many plans and estimate that it may take as much as two years for these to fully materialize. It is hoped that eventually the people who have shown the greatest applicability might form the nucleus of a consulting group capable of dealing with problems affecting all operating areas.

In conclusion there are only two more points that I would like to make that may be of particular interest and benefit to you. Every type of program activity requires a channel for communication, a means of obtaining and disseminating information and of the many agencies who have offered themselves, I would refer you to the Society for Operations Research and the Institute of Management Sciences as the most ideal sources for background

information. For workshop program material, I can endorse both the National Institute of Management, Inc. in Cleveland, Ohio and the Operations Research Institutes, Inc. in New York City, both of whose work I am quite familiar with and believe to be outstanding. Here you can obtain first-hand reliable background information directly from people who are experts in their particular fields of endeavor, outstanding in ability and genuinely enthusiastic about their subjects. And the material is presented in such a fashion to make it adaptable to any approach you care to make.

USE OF ENGINEERED STANDARDS IN OVERHEAD OPERATIONS

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I now see why I am the last speaker, after three of my Army colleagues. First, all these brilliant, ingenious devices and techniques that I was going to claim for the Navy -- they have already claimed for the Army. Secondly, they have left me no time.

Lord Kelvin once said that you cannot control a process unless you can measure it. My Bureau in the Navy Department, the Bureau of Supplies and Accounts, as other government agencies, has for years been utilizing statistical measurements for control purposes.

Recently, as a refinement to statistical techniques, we have adopted an engineered time standards program. An engineered time standards program, by our definition, is a program where we set time standards on all our operations, utilizing techniques such as time study, methods time measurement, Yale and Towne predetermined time standards and ratio delay studies.

The Bureau of Supplies and Accounts is one of seven bureaus of the Department of Navy located in Washington, D. C. The principal Navy-wide responsibilities of the Bureau of Supplies and Accounts are procurement, inventory control, storage and issue of material for the Navy, as well as transportation, accounting and disbursing; in short, complete logistic support to get the right material at the right time in a right amount at the right place and to account for it.

To give you an idea of the size of the job, the Bureau's budget for these functions is about $300 million per year. We handle about 1 million measurement tons per month. We process over 1 million requisitions of material per month. We have 175 million square feet of storage space and almost all filled. We employ an average of 50,000 civilian employees in the Bureau of Supplies and Accounts alone and more than half of these 50,000 are engaged in clerical functions. We have over 50 major field activities, all over the continental United States and the world, performing these functions.

It is apparent from these figures that by size alone, an engineered time standard program should be profitable in what we term our supply operations, clerical and paperwork, warehousing, electric accounting machines and public works maintenance.

We originally became interested in engineered time standards due to a capacity study that the Bureau of Supplies and Accounts initiated. The intent of that study was to determine the capacity of one of our supply depots in case of mobilization.

During that study it soon was realized that the tool of engineered time standards had more potential than the capacity study.

The Chief of the Bureau of Supplies and Accounts, then agreed to permit a pilot study of engineered time standards to determine whether time standards were applicable in our supply operations. As a result of the pilot study, we definitely proved that time standards are applicable to supply or overhead operations.

At this time we have six installations using engineered time standards, and plan to commence six more in the near future.

Let me describe the objectives of our program. Basically, our objectives can be categorized into three factors. We look at engineered time standards as a management tool that can be utilized at all levels of supervision. We feel that our supervisors who have this management tool available to them can distribute their work load to their employees more effectively and also can appraise their employees more effectively.

We now have a measurement to determine whether Mary Jones, who is sitting out there typing documents, is giving us a fair day's performance, an outstanding day's performance, or a poor day's performance. Where Mary Jones has consistently been giving us an outstanding performance, we have utilized the incentive award system. We have granted awards to outstanding employees, who have consistently maintained an increased productivity.

The second objective of our program is that we feel that we can determine the impact of new work or new procedures prior to their installation. We are notorious in government and probably so is commercial industry for making changes based on "guesstimates" or intuitive knowledge. Many of these changes are for the purpose of achieving manpower improvements, and someone has determined that they will achieve this additional manpower. But they have been determined intuitively and the manpower claimed is not adequately substantiated.

With time standards we feel we can measure the proposed system, how many manhours it will taken, and we can measure the existing system and then actually compare the manhours that the proposed and existing system or procedure of these systems will actually require. Then determine whether it is wise for us to make these changes and then perhaps, many of these changes that we generate so freely will be completely discontinued.

The third objective of our program is that we feel engineered time standards will and have helped us determine our manpower requirements.

We set standards on just about 90 percent of our employees at this time in the areas that we have gone into. By knowing the standards, by knowing our workload, we can staff accurately. No longer do we feel that we have been subject to the normal criticism that we have two employees for one day's work. We will attempt and we have in the areas where we have standards now just about completely eliminated all idle time from our system.

As an aside, it always interests me that in production shops or straight manufacturing areas, it is rare when you approach an employee who doesn't know exactly what her supervisor wants production-wise day by day. She can tell you "I have to produce to meet standards 100 items a day." Yet in clerical areas, warehousing areas, or the overhead areas it is just as rare to find an employee who knows what the supervisor wants in those areas as far as daily production is concerned.

Engineered time standards we feel and have shown can give us that type of information. And that information has a great psychological advantage, because basically we feel that most normal human beings attempt to give you what you want if what you want from them is a fair request. And we feel, if our standards are fair and consistent, we can improve our production that way.

I was going to go into the details of how we select our people and the testing procedure and how we are careful as to who we select for this program.

At this point, I will just say ditto to Mr. John Nevros' speech, we do about the same thing the Army does in selecting and training our people, with the exception that we use the method time measurement system in lieu of BMT.

As you all know, the case history of labor management relations, time study has run up a long record for making trouble. In the past six years nearly 25 percent of all manhours lost from work stoppage was completely caused by arguments about measuring a worker's performance.

When we started our program we were well aware of this sensitivity and caution was our password.

When we initiate our standards program in any installation, we conduct a complete and thorough indoctrination for all personnel concerned, that is, top management, commanding officers, executive officers, all his military staff, all his supervisors, all employees either in groups or individual contact.

We emphasize extensive publicity. The very first steps are newspaper releases to both local house organs and to the local newspaper; we contact the Congressman of the area. We pass out to every single employee at that activity a description of our program, as to how we are going to do it and what we are going to do. And this passout is depicted very nicely in cartoon form.

We explain to our employees that this is not a speed-up program. We have no such intention. But what we are trying to do is arrange a fair working agreement, a fair day's work between the employee and her supervisor.

As mentioned previously, the techniques that we use are time study, methods time measurement, the Yale and Towne pre-determined standards and ratio delay studies.

I would like now to demonstrate to you two examples of areas where we have set standards. One is the procurement branch, and the other is in our electric accounting machine room in the key punch branch.

In the procurement branch, we have a branch that is involved in the actual purchasing of material for the Navy under contract and also orders for material under contract. In this branch we had to set 27 standards. These 27 standards were the standards utilized by the supervisor for distributing workloads and for appraising hourly and daily production of the employees working for the supervisor. From our management point of view and top management we have pyrimided these 27 standards into 10 standards.

Slide, please.

Utilizing these 10 standards, we obtain the performance effectiveness of the entire branch.

I would like to point your attention to standards number 4. Standards number 4 was set in a contract unit. The operation is typing contracts. The unit of measure is contracts. The standard's hours is .1983 standard hours, or 40 contracts per day. Naturally, we type more than one type of contract. Actually, in this particular branch, we type seven different types of contracts.

Next slide, please.

Here are the seven contracts that we type in this contract unit. As you note, we have set standards for each one of these different type contracts. However, in order to pyramid this, we have to take a frequency study, and I would like to point out at this time that we have to utilize this technique considerably. However, we have gone through a great deal of effort and pain to insure that our frequency percentages are statistically significant.

In seven contracts, with these standards, we have these frequencies. Taking the standards times the frequency we then determine the weighted average--1983, or 40 contracts per day, which is the requirement for typing.

Let us go into this ship stores' contract, a special type contract, and see how we developed this standard of .19473. We have found, and this is true in most of our clerical areas, that our productive work falls into two categories: productive measured and productive non-measured.

The productive measured work is work that we can actually measure, utilizing our techniques. We classify as productive non-measured work tasks due to their variedness, and their unpredictableness, they are not profitable to measure. Therefore, on that type of work we use our ratio delay technique.

Let us look at our productive measured work. First, we set up our productive measured work in a formula, set up time, which is a constant. This is similar to the production terminology of "make-ready". The employee gets her documents together, obtains her carbon together, inserts it in a typewriter and actually finishes her typing, then takes it out of the typewriter, removes the carbons and lays it aside. This is a constant for this type of contract.

The next element in our formula is a typing constant. What we classify as a typing constant is the typing that the employee performs in filling in the blocks which are on the contract. These blocks include such things as contract number, employee's initials, contract name, appropriation number, contractor's name, and items such as that. She fills in specific blocks and there is no variableness and that is what we call a typing constant.

The next item in our formula is typing formula for line item or items. Actually we order more than one item on each contract, and the more items per contract the longer it naturally will take. Therefore, that was our first variable: typing variable for line items.

By the way, the values here are stated in TMU's and those of you will know who are familiar with MTM that a TMU is a time measured unit.

Each TMU is equivalent to 1/100 thousandth of an hour. Therefore, a decimal point over here would give you the time in standard hours.

The next variable is the continuation sheet. Naturally, each sheet can only have so many line items. As you go into more items, you need a continuation sheet. That is a variable.

A formula for typing a ship stores contract in this area is our set-up time, our typing constant for the heading, the typing variable for the line item, times the number of line items, plus our typing variable for the continuation sheet, times the number of continuation sheets.

In this particular type of contract, we found that there were four line items of the contract and no continuation sheet. Now, the total of all those values gave us 11,441 TMU, that is what we call productive measured time. But we still have to give our employee time due to productive non-measured time.

To accomplish that, we then utilized ratio delay studies. As you all know in ratio delay studies the most significant point is to insure that the number of observations you take are statistically significant. We have in all areas insured that.

The type of things that we feel are not profitable to measure, are elements such as distribution, filing, correcting errors in the contract, official talking, and official walking.

To determine the total productive time, measured and non-measured, we took these percentages times the productive measured time and came up with this value: 16932 TMU or .169 standard hours.

In this particular area we have established that we will grant our employees a 15 percent allowance. Fifteen percent times this figure here gives us the total TMU allowed: 19472 or standard hours allowed equals .19473 to type a ship stores contract.

The scope of the standards is always included in all our documentation to prevent future problems.

Now, I would like to go into how we obtained our typing time and our set-up time.

First, you will notice our set-up time was 1701 TMU. Then we have a typing formula again, which is the same as I mentioned previously, constant, variable line item and variable continuation sheets.

Let us follow through now and see how we obtain the 1701 TMU for set-up times.

Next slide, please.

This is our operations summary for make ready. In order to determine the time for this operation, we broke down the operation into elements. There were 24 elements in this make-ready or set-up for typing. Each element has an analysis chart reference, which is our own local reference number, and an element time.

I might add that when you see SD that is an element that we have established standard data for and we can pick out these elements from our standard data.

Let us follow through these elements. Element 4, Fold over top sheet of requisition, CU-16. Element time 71.2. Just to give you an idea of how detailed this study is, 71.2 TMU's is approximately equal to two seconds.

Next slide.

Here is CU-16: Fold over top sheet of requisition. This 71.2 was established by methods time measurement. The basic motion pattern for this element is as follows: reach to bottom of turned sheet, turn over top sheet, release sheets. The total of all the elements was equal to 1701. That is how we established our set-up time.

Next slide.

To get our typing time, we utilized methods time measurement again. Here we set up every element in typing and actually measured them by methods time measurement, and by "element" I mean press tab key, type capital letters, type small letters--every element we observe that an operator utilizes in typing.

Here is an example of one element: Shift space with tab key, the first time. The motion pattern for this is as follows: reach to tab key, press key, machine time, release tab key, and reach to home keys -- 16 TMU or approximately 1/2 a second.

Each element an employee utilizes in typing was measured by this technique. Then all this information was documented on a typing summary sheet. The typing summary sheet here has all the elements that were involved in typing a ship stores contract.

On this line here we actually have the elements that the employee had to utilize in typing. For example, the first thing she does in typing a contract is she puts her initials on the left hand corner and order number. To do that she has to use one of these elements, two of these, six of these; to type lower case elements, two of these, and then every element in typing a contract is then summed up and have been called frequencies here and then the total, 5973 TMU for typing up to this point.

However, in typing contracts, we notice that every once in a while there has to be a note to the contractor, giving contract specifications regarding a particular point. In order to determine that, first we went through the same procedure to determine the note to the contract. It came out that was 1,096 TMU's to type the note on the contract.

However, that was not done on every contract; it was only done on 27.2 percent of the contracts. Therefore, taking 27.2 of this value we get 298 and, in order to determine the typing constant, we take 5,973 plus 298, which gives us the typing constant.

To determine the time to type line items, we utilized the same procedure here and totaled up the number of items involved, subtotaled it, and got the time to type varied line items -- 856.7.

That was the procedure we utilized in procurement. I would like to add that when we entered the procurement branch the branch was about 60 percent effective. That is all the man-hours they were utilizing, compared to the manhours against standards was only 60 percent effective. At this time they are close to 100 percent effective in this particular depot.

The next example I would like to show you is how we set standards in one area of the electric accounting machine room.

Here there are three major areas in the electric accounting machine room: First, the clerical area; second, the key punch and key verify area; and third, the tabulate. This is the final result.

Let us see how we set standards in the key punch area of the electric accounting machine room.

The first thing we did was similar to what we did in typing. We established the set-up time. Because of the nature of the problem we decided we would establish a set-up time per card basis, 26.0.

The next variable we noticed in the key punch area was the time it actually took the operator to key punch. It depended on the condition of the source document. So we set up criteria as to what do we mean by different types of source documents. A good source document was a document where the items to be punched on the document were in the same order as the key punch needed them to be, plus it was a legible condition. Fair condition of document was where it was the same order as it must be punched but poor legibility. Poor was data on the source document was complex order and poor legibility.

We then classified every type document that was routed to our key punch room. By that I do not mean that we had to take every requisition that came in and determine whether it fell into one of these three categories; but a requisition was always good because a requisition came in in the proper order and was always typed. Changing stock numbers was always fair for the reasons as described here.

Then, we determined how long it takes to key punch a card where the source document was good, fair or poor, and these are the values we established for that.

In addition to the key punch operation, there is a duplicating operation in the key punch area. This was established by a time study, and it is 2.2 TMU.

Another variable in the key punch was that you had an error time value, and there were two different correction methods. These two values are in TMU's and were established by measured time measurements.

We then put all this information into a formula, and there is our formula: set up for card, plus allow per column key punched, times number of columns key punched, plus allowance for column duplicated, times number of columns duplicated, times card volume.

It sounds like a lot of work, but it really isn't that difficult, because every job we have, for example, changing stock numbers, we establish what the standards for that job is and the only variable is to determine how many cards are involved and in that way we can easily determine standards for any particular job that goes into the key punch area.

What have our results been to date?

We have set standards profitably, and I emphasize the word "profitably", in the following areas: paperwork, typing, electric accounting machines, warehousing, public works maintenance, traffic management and pay disbursing.

And the reason I emphasized the word "profitably" is because in all these areas the cost for setting the standards was more than returned in the benefits we have derived.

Generally, our employees are meeting our standards in these areas. Group performance in all the areas we have been to date have leveled off to about 90 percent of standards.

I would like to point out here that we do not use a wage incentive program at all except we utilize our award incentive; and therefore, we feel that 90 percent is a good figure.

To date we have had no serious personnel problem.

Was it profitable?

On this slide we have taken one depot where we have set such standards. We have actually accumulated costs, and this is all the costs. We utilized a management consultant, namely the Methods Engineering Counsel of Pittsburgh, and, as you all know, they are rather costly. Including that, plus all the employees involved in this program, we have just about reached a break-even point at this particular depot, and we feel that further profit from this program will be generated at this level.

We have also utilized this technique for comparing office equipment. We are deluged in the Bureau of Supplies and accounts by salesmen who have all kinds of office equipment which they claim will save us numerous manhours, and in many cases we buy this equipment, not necessarily that the manhours are saved. They are eye-catching types of equipment and someone thinks that it will save us manhours and we thereby purchase it. Recently a well known file producer approached us with a new type file. It was definitely eye-catching and he promised many manhours saved by the utilization of this file. Our ETS analyst compared the manhours involved in the proposed filing system with the manhours utilized in our present filing system, and it was substantiated that the manhours saved by the proposed filing system was naught. There were no manhours saved. Our ETS analyst recommended that the filing equipment be not purchased and it was not purchased.

Recently, as most agencies in the Department of Defense, we had to undergo the very lengthy job of converting all of the Navy stock numbers into the Federal stock numbers. This was quite a task. All bin stock numbers had to be changed, all the stock records had to be changed, and all the paper documents in the system had to be changed.

When this work was presented to us, most activities were requested to determine how much it was going to cost them to make this change, and most activities presented a figure; but, in most cases, it was just a good intuitive guess.

In the areas where we had engineered time standards, we actually pre-planned the entire conversion job. Detailed procurement punch standards were set. Every basic motion was detailed. The cost for making the conversion was then estimated. And in this particular area the cost was within 2 percent of the actual cost to make the conversion.

We set standards in the traffic management area. In this area we even entered with trepidation. Here was an area where traffic managers take bills of lading and rate them. They rate them according to the type of material being shipped and destinations. What makes this rating so difficult is that traffic managers from their years of experience retain a certain amount of knowledge and can look at certain bills of ladings and know immediately what the rates should be. In other cases, they have to refer to reference books. If they do not find them in one set of reference books, they go to another set, and they continue until they find the information they need to rate the bills of lading. Rating is a very important part of this bill of lading process, in that it determines how much the contractor is going to receive for shipping the material.

We set standards in this area and they worked most effectively. Originally the effectiveness of the traffic management branch was about 60 percent. They are now operating at about 95 percent, and the savings we have derived in this area have more than offset the cost.

Before I completely lead you astray, let me say one thing: everything I have told you to date is the rosey picture of setting standards in overhead operations.

There have been a hell of a lot of problems. One major problem is always complete support, and that is one basic need for a program like this. Where this program is being installed, you must have the support of management.

In summary we feel that we have set attainable standards profitably in areas normally excluded from a time standards program. We have set these standards utilizing career government employees.

We have, we feel, in engineered time standards a management tool, not a panacea, not God's answer to an engineer's dream, but a tool which will assist us, in a small way, in fulfilling our basic mission, which is complete logistic support and at a minimum cost to you, the taxpayer.

Thank you.

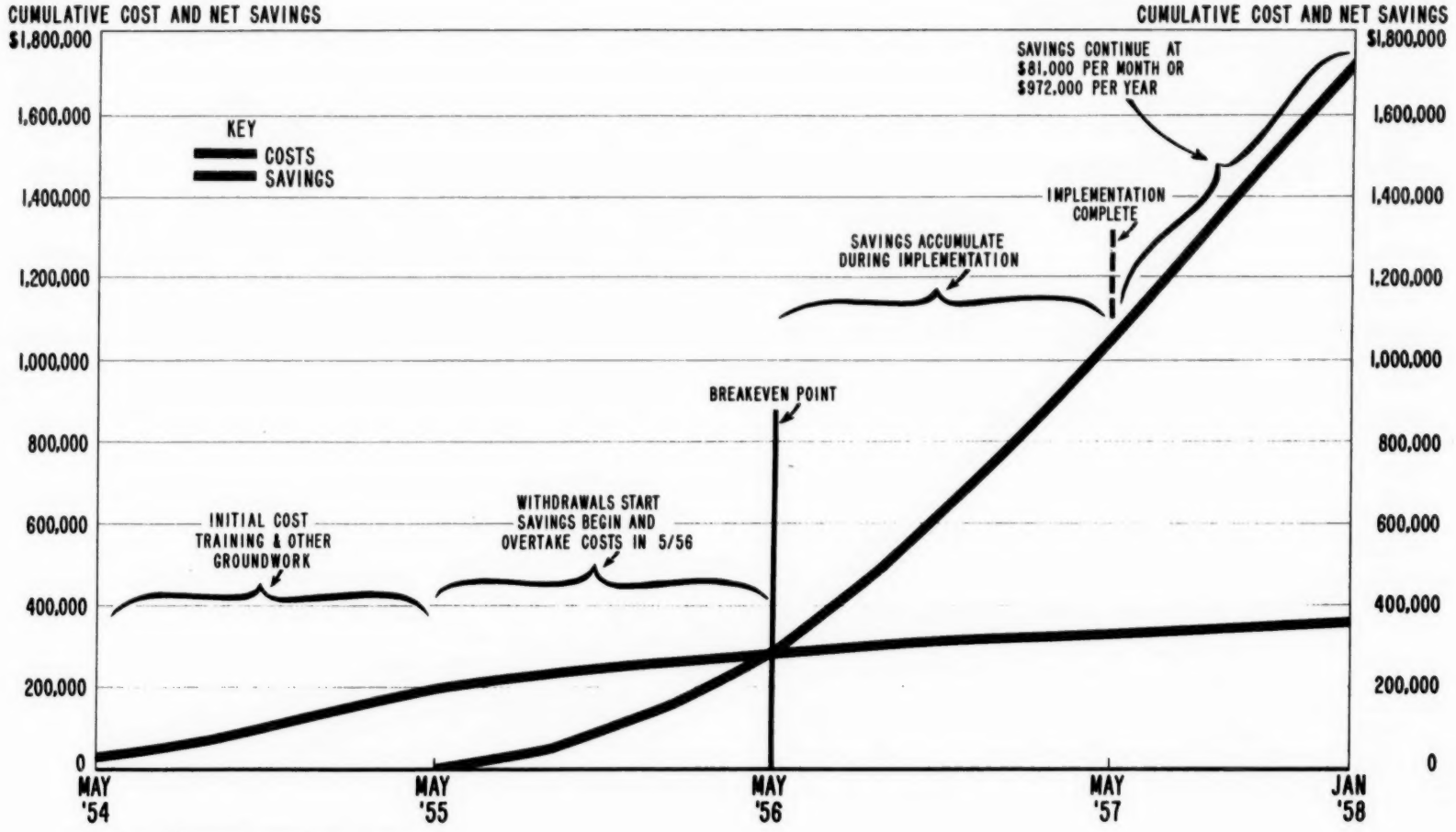
ENGINEERED TIME STANDARDS

PROCUREMENT BRANCH

ANALYSIS OF TIME STANDARDS

STANDARD NUMBER	UNIT	OPERATION	UNIT OF MEASURE	STANDARD HOURS	POTENTIAL PRODUCTION UNITS PER HOUR	POTENTIAL PRODUCTION UNITS PER DAY
1	Contract	Orders placed on contract (regular)	L.I. processed	.1212	8.3	66
2	Contract	Orders placed on contract (Ship Stores)	L.I. processed	.0899	11.1	89
3	Contract	Verification of typed contracts	L.I. completed	.0430	23.3	186
*4	Contract	Type contracts	Contracts	.1983	5.0	40
5	Requisition	Orders placed on requisition	L.I. completed	.1404	7.1	57
6	Requisition	Type requisitions	Requisitions	.1838	5.4	43
7	Buyers	Regular purchase orders placed	Line items	.3200	3.1	25
8	Buyers	CSS Purchase orders placed	Line items	.1290	7.8	62
9	Typist	Verification of typed purchase orders	L.I. completed	.0430	23.3	186
10	Typist	Type purchase orders	Purchase orders	.1928	5.2	42

ETS PROGRAM NSD, BAYONNE
ESTIMATED COSTS AND SAVINGS



PREPARED BY: MANAGEMENT ENGINEERING DIV., BUSANDA
27 OCTOBER 1955

17-A-2

17-A-2

REQUISITION & ORDER SECTION

CONTRACT UNIT

TYPING SYNTHESIS

STD NO.	TYPE OF DOCUMENT AND VARIABLES	STANDARD HOURS AVERAGE DOCUMENT	FREQUENCY OF OCCURRENCE	WEIGHTED AVERAGE
1	N140S-MATERIAL REGULAR N140S-PROVISIONS GS-MATERIAL (a) Number of line items per document (1.6) (b) Number of continuation sheets required	.17905	21.0 %	.03760
2	N140S-SHIP STORES (a) Number of line items per document (4.0) (b) Number of continuation sheets required	.19473	34.0 %	.06621
3	SERVICE CONTRACT (a) Number of pages (average document selected)	.24262	15.0 %	.04367
4	N155S-GAS CONTRACTS (a) Number of pages (average document selected)	.30491	.4 %	.00122
5	ASP-ARMED SERVICES PETROLEUM (a) Number of pages (average document selected)	.18836	17.0 %	.03202
6	N600S-IBM CARDS AND AUTOMOTIVE SPARE PARTS (a) Number of pages (average document selected)	.35587	.6 %	.00214
7	RUBBER STAMPS (MEMO) (a) Number of line items per document (2.6) (b) Number of continuation sheets required	.17152	9.0 %	.01544

WEIGHTED AVERAGE PER DOCUMENT = .19830

REQUISITION & ORDER SECTION

CONTRACT UNIT

N140S - SHIP STORES CONTRACT (DD738)

ANALYSIS OF STANDARD

FORMULA:

(A)	Set up time (constant)	1701	
(B)	Typing constant (Headings, etc.)	6272	
(C)	Typing variable (line item)	867	
(D)	Typing variable (continuation sheet)	1197	
(K)	Number of line items	4	(at NSD Bayonne)
(N)	Number of continuation sheets	0	

VARIABLE RELATIONSHIP

K - Number of Line Items	N - Number of Continuation Sheets
1-4	0
5	.25
6-20	1.00
21-40	2.00
41-60	3.00
61-80	4.00
81-100	5.00

MEASURED TIME = A + B + CK + DN
= 1701 + 6272 + 867 (4) + 1197 (0)
= 7973 + 3468
= 11441

(CONTINUED)

ANALYSIS OF STANDARD (CONTINUED)

		TMU's
MEASURED TIME		11441.0
Ratio Delay Allowance		
Productive Non-Measured		
Distribution	15.2%	
Filing	10.6%	
Correct errors	6.0%	
Official talking	8.1%	
Official walking	8.1%	
	48.0%	5491.7
		16932.7
Personal Allowance	15 %	2539.9
Total TMU's Allowed		19472.6

Standard Hours Allowed = .19473

SCOPE OF STANDARD

Includes all work necessary to type a Ship Stores Contract Order. Also included in the standard are allowances for the following: (1) Distribution (2) Filing (3) Correcting Errors. It was found by the analyst that the Line Item variable did play a significant role, in the actual typing required. The number of Line Items involved will determine the number of Continuation Sheets necessary. This factor was considered and included by the analyst in the standard. The standard was based on an average number of Line Items Per Document (4.0). Provisions have been made to adjust the standard if the average Line Items Per Document changes. See Table for detailed breakdown by Line Item.

REQUISITION & ORDER SECTION

CONTRACT UNIT

N140S-SHIPS STORES CONTRACT (DD738)

(A) SET UP TIME = 1701 TMU
REFERENCE: Operation Summary-7

(B) TYPING FORMULA = CONSTANT + VARIABLE (LINE ITEM) + VARIABLE (CONTINUATION SHEETS)

CONSTANT	TYPE	TMU	FREQUENCY	LEVELED TIME
All information excluding note to Contractor & Line Item		5973.8	100%	5973.8
Note to Contractor		1096.3	27.2%	298.2
				6272.0

TMU: 6272
REFERENCE: Typing Summary-16

VARIABLE (Line Item) = 666.6

TMU: 667
REFERENCE: Typing Summary-16

VARIABLE (Continuation Sheet) = Set up time + type heading
= 436.6 + 760.6
= 1197.2

TMU: 1197
REFERENCE: Operation Summary-8 & Typing Summary-15

OPERATION SUMMARY

DATE STUDY NO.

ORGANIZATION	SUB/DIVISION	ANALYST
PROCUREMENT BRANCH	CONTRACT UNIT	
OPERATION		SHEET NO. OF SHEETS
TYPE CONTRACT ORDER		

NO.	ELEMENT DESCRIPTION	ANALYSIS CHART REF	ELEMENT TIME TMU	OCCURRENCES PER PIECE OR CYCLE	LEVELED TIME
	ASSEMBLE SUPPLIES & INFO TO BE TYPED				
1	Obtain folder from basket	SD-1	42.3	1	4.23
2	Open & close folder	CU-1	87.2	1	87.2
		CU-2			
3	Remove requisition	SD-1	23.0	1	23.0
4	Fold over top sheet of requisition	CU-16	71.2	1	71.2
5	Obtain & lay aside pencil	SD-1	39.0	1	39.0
6	Obtain & lay aside record pad	SD-1	61.0	1	61.0
7	Write: Contract & order no. doc no & no. of items	CU-18	430.0	1	430.0
8	Move requisition near typewriter	SD-1	35.8	1	35.8
	SET UP FOR TYPING				
9	Obtain blank form (DD738) from desk	SD-1	40.3	1	40.3
10	Move form to typewriter (turn body)	BD-1	121.0	1	121.0
11	Insert form into typewriter	TY-3	62.6	1	62.6
12	Straighten & line up paper	TY-4	81.2	1	81.2
13	Tighten typewriter roll	TY-5	12.1	1	12.1
14	Position sheets under hold down clasp	TY-6	7.6	1	7.6
15	Position carriage to exact line & space	TY-8	44.7	1	44.7
	REMOVE TYPED DOCUMENT - ASSEMBLE - LAY ASIDE				
16	Turn folder over(Type con, name & address)	SD-1	35.8	1	35.8
17	Remove form from typewriter & place on desk	TY-19	66.5	1	66.5
18	Obtain & lay aside pencil	SD-1	39.0	1	39.0
19	Write: Initials & date on requis.	WR	108.0	1	108.0
20	Open & close folder	CU-1-CU-2	87.2	1	87.2
21	Assemble(DD730)with requisition	CU-6	32.8	1	32.8
22	Attach with clips	PC-2	77.4	1	77.4
23	Place documents in folder	SD-1	35.8	1	35.8
24	Lay aside folder	SD-1	59.0	1	59.0

TOTAL TIME ALLOWED FOR 1700.5

METHODS ANALYSIS CHART

ORGANIZATION PROCUREMENT BRANCH		DATE				REFERENCE NO.
SUBDIVISION		ANALYST				SHEET NO. OF SHEETS
DESCRIPTION-LEFT HAND	NO.	LH	TMU	RH	NO.	DESCRIPTION-RIGHT HAND
CU-15 (CONTINUED)						
Turn sheet over	2	M10B	24.4			
Release sheets	2	RL1	4.0			
			29.2	ET	2	Look for next order #
			234.4			
CU-16 FOLD OVER TOP SHEET OF REQUISITION						
Reach to top sheet		R6B	8.6			
Grasp		G1B	3.5			
Turn top sheet		M14B	14.6	R6E		Move hand in position
Release top sheet		RL1	2.0			
Reach to bottom of turned sheet		R6B	10.1	R8B		Reach to turned sheet
Contact sheet		G5	-	G5		Contact sheet
Crease sheet	3	M4C	21.9	M4C	3	Crease sheet
Release sheet		RL2	-	RL2		Release sheet
Return hand to rest		R10E	10.5	R10E		Return hand to rest
			71.2			
CU-17 FILL OUT PRODUCTION REQUEST FORM						
			324	WB	18	Codes from & to; phone / date (2)
			40	WB	4	4 slants
			35	WB	3	3 M1C + 1 P1SE (3 check
			44	WB	2	Write capitals (2 letter
			128	WB	8	Write small letters
			51	W3C	9	Move pencil on form
			622			

METHODS ANALYSIS CHART

ORGANIZATION PROCUREMENT BRANCH		DATE			REFERENCE NO.	
SUB/DIVISION		ANALYST			SHEET NO. OF SHEETS	
DESCRIPTION-LEFT HAND	NO.	LM	TMU	RM	NO.	DESCRIPTION-RIGHT HAND
TY-10 REPEAT LINE & SPACE						
Press tab key		M1A	1.7			
Machine process time			6.8			
			8.5			
TY-11 SHIFT SPACE WITH TAB KEY - FIRST						
Reach to tab key			5.6	R3A		
Press Key			1.7	M1A		
Machine process time			9.0			
Release tab key			-	RL2		
Reach to home keys			-	R3A		
			16.3			
TY-13 TYPE LOWER CASE LETTER, SYMBOL OR SPACE						
Reach to key		R1Az	2.0			
Contact		G5	-			
Move key down		M1A	1.6			
Raise finger		RIE*	-			
Lose contact		RL2	-			
			3.6			
*Limited out by next finger reach						

TYPING SUMMARY
3L0-H 30DAY-MTM-13

STUDY NO. 16

ORGANIZATION	SUB/DIVISION	ANALYST
PROCUREMENT BRANCH	CONTRACT UNIT	
TYPE DOCUMENT NAVSUP 1140s-SHIP STORES CONTRACT ORDER DD738		SHEET NO OF SHEETS

ELEMENT DESCRIPTION	Position Carriage to margin and index one space TY-16 (39.5)	Position Carriage to Line and Space by hand TY-3 (44.8)	Type 1-1 Upper Case Letters TY-14 (17.8)	Type Numbers TY-15 (8.7)	Repeat Line Spacing TY-50 (8.5)	Type Lower Case Letter TY-13 (3.6)	Type Additional Upper Case Letters TY-13 (3.6)	Eye Travel (Maximum) 20.0	Eye Focus 7.3	Shift Space with Tab Key Set TY-11 (16.2)	Set Tabs TY-18 (76.4)	Clear Tabs TY-17 (35.1)	TOTAL
INITIALS & ORDER #		1	2	6		2	2	2	1				
NUMBER OF SHEETS				1		15		2	1				
DATE OF ORDER		1	1	4		4							
REQ # & DEL DATE		1	3	21		21	1	7	3.5				
DISCOUNT TERMS		1	1	3		5		2	1				
SUPPLIER	3	1	9	3		60		8	4				
SHIP TO	.5	1	5.5	15		28		5	2.5				
MAIL TO & DEST	1.5	1.5	5	7		30		7	3.5				
TYPE ORDER		2	6	4		26		6	3				
QUANTITY & CONTENTS		1	2			21		2	1				
SIGNATURE		1	1			6	18						
CLASS & PRIORITY		1	2	2		14	4	4	2				
SCHEDULE			1			24	19	4	2				
COST & APPROPRIAT.		2	3	41		27	3	16	8				
DISTRIBUTION		5	3	5		15	115	10	5				
ASSEMBLE BLDG 31		.5	.5	1		2	6	1	.5				
FREQUENCY	5	20	45	113		300	168	76	38				
SUB TOTALS	152.5	894.0	801.0	614.1		1080.0	604.8	1520.0	274.4				5973.8
NOTE TO CONTRACTOR	4	1	4	3		145	23	10	5				
SUB TOTALS	122.0	44.7	71.2	17.1		522.0	82.8	200.0	36.5				1096.3
						FREQUENCY OF NOTE TO CONTRACTOR							27.3
						NOTE TO CONTRACTOR							298.2
LINE ITEM	1	1	4.5	20		52		8	4	5	5/4	5/4	
SUB TOTALS	30.5	44.7	80.1	114.0		187.2		160.0	292	81.5	95.5	43.9	866.4

The Standard for Key Punching & Key Verifying is summarized below. All allowances have been included.

KEY PUNCH & KEY VERIFY TIME VALUES			
SET-UP PER CARD	TIME VALUE PER CARD COLUMN		CONDITION OF SOURCE DOCUMENT
	KEY PUNCHED	DUPLICATED	
20.0	9.1	2.2	A - GOOD
20.0	12.0	2.2	B - FAIR
20.0	14.8	2.2	C - POOR

ERROR TIME VALUE PER ERROR CARD	CORRECTION METHOD
470	A. Destroy error card and remove document from batch.
1093	B. Remake error card and insert new card in proper place in lot.

KEY PUNCH FORMULA: Set-up per card + (Allowance Per Column Key Punched X Number of Columns Key Punched) + (Allowance Per Column Duplicated X Number of Columns Duplicated) X Card Volume

KEY VERIFY FORMULA: Set-up per card + (Allowance per Column Key Verified X Number of Columns Key Verified) + (Allowance Per Column Duplicated X Number of Columns Duplicated) X Card Volume (Error Allowance per error card X Number of Error Cards)

DEFINITIONS OF SOURCE DOCUMENTS

A. GOOD - Data of source documents are in same order as they must be punched, normal legibility and handling of documents.

B. FAIR - Data not presented in the same order as it must be punched, or source documents good but with poor legibility or requiring excessive handling.

C. POOR - Data on source documents in complex order and with poor legibility or requiring excessive handling.

NOTE: Short one-time jobs of 5,000 cards or less should usually be classed as POOR source document media for the reason that operators obtain good production just when the punching job is finished.

ILLUSTRATIONS OF LINEAR PROGRAMMING*

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Linear Programming can be defined as a mathematical theory designed to select an allocation of limited resources that fulfills the requirements of various activities so as to yield the best returns. Although this definition is so vague as to be almost useless, it does render plausible the assertion that the linear programming model has found application in many industrial situations by flexible, and sometimes quite ingenious, interpretations of the meanings of resources, requirements, activities, and returns. What the definition does not delineate satisfactorily are those mathematical aspects of linear programming that are the source of the success of the theory in providing numerical answers to practical problems. It is the purpose of this paper to illustrate some of the mathematical features of the theory that set it apart from more general areas of optimization. This will be done by means of examples in miniature chosen from several important fields of application. Preaching by example as it were, the mode of presentation is informal; for the reader who may want more detailed information, some historical remarks and precise references are given at the end of the paper.

The first example will be familiar to anyone who has been exposed to a standard textbook treatment of the differential calculus. It is put forward as an illustration of what linear programming is <u>not</u>.

EXAMPLE 1. From a square sheet of tin of side 10", we can make an open box by cutting four equal squares out of the corners and turning up the sides. Find the dimensions of the box of greatest volume. (See Figure 1 attached).

This problem has all of the features of the verbal definition of linear programming given above. The limited resource is the amount of tin available. If the common length of the sides of the squares to be cut from the corners is denoted by x, we have the constraints:

$$0 \leqq x \leqq 5 .$$

The returns from the activity of making the box are measured by the volume V of the resulting box. It is clear from Figure 1 that $V = x(10 - 2x)^2$. A careful treatment of this problem by the methods of calculus might be given along the following lines: Since $V = x(10 - 2x)^2$ is defined and continuous at each point of the finite closed interval $0 \leqq x \leqq 5$, there is certainly an absolute maximum at some point of the interval. The

*The preparation of this paper was supported, in part, by the Office of Naval Research Logistics Project, Department of Mathematics, Princeton University.

maximum may occur at some point interior to the interval, or at either one of the end-points. If the former is the case, $dV/dx = 0$ at the point. Thus, the search of the absolute maximum can be made by examining the values of V at those points for which $dV/dx = 0$ and comparing these with the values of V at the ends of the interval. Since this problem is typical of the "practical" problems encountered in calculus textbooks, one can easily see that the required maximum does not occur at an endpoint, that the maximum value of V is 2000/27, and is attained at $x = 5/3$, the unique interior point for which $dV/dx = 0$.

This example differs from the typical linear program in three important respects:

1. The objective function of a linear program is linear (contrasted with $V = x(10 - 2x)^2$, which is non-linear).

2. Generally, a linear program is a problem in many variables (contrasted with the single variable x).

3. Typically, the variables of a linear program are subject to general linear constraints relating several variables (contrasted with the simple limitations on the size of x: $0 \leq x \leq 5$).

To examine the consequences of these characteristic features, suppose first that the returns from making the box were measured not by V, but by some linear function of x , say

$$z = 10x + 30 .$$

In this case, it is certain that the maximum will occur at one of the end-points (see Figure 2 to compare the graphs), and no calculus is needed for the solution. The search for a maximum is made by examining the values of z at the ends of the interval. (See Figure 2 attached).

The conclusion is forced upon us that linear programs are a rather special category within the wide class of extremal problems. They are recognized by the prominent appearance of linearity, both in objective function and constraints. Ordinarily, this suggests a first approximation in the solution of a physical problem; however, this is only partially true here since there are several functions (such as costs and profits) that are exactly linear in static economic models. The linearity of the objective function implies that its extreme values are to be found on the boundary of the region of admissible values of the variables (i.e., the region where the limitations and requirements are met). The linearity of the constraints gives this region a particularly simple geometric character (we shall see that it is always a convex polyhedron). However, an example in one variable cannot illustrate this feature adequately; it will only become apparent when more variables are added to make a more realistic example.

EXAMPLE 2. (A Transportation Problem) A manufacturer has two warehouses, with 90 tons of a product in the first and 70 tons in the second. He must supply three markets, with 50 tons required at the first, 70 tons required at the second, and 40 tons at the third. Transportation is available from either warehouse to any marked but the transportation costs vary. From the first warehouse, the costs are $7 per ton to the first market, $5 per ton to the second market, and $8 per ton to the third market. From the second warehouse the costs are $2 per ton to the first market, $3 per ton to the second market, and $4 per ton to the third market. The problem is to carry out the distribution at a minimum transportation cost. (These data are presented in Figure 3). (See Figure 3 attached).

The unknowns in this problem are the amounts to be shipped from each warehouse to each market. Therefore, it is natural to use a double subscript, as shown in Table 1.

	M1	M2	M3	=
W1	x_{11}	x_{12}	x_{13}	90
W2	x_{21}	x_{22}	x_{23}	70
=	50	70	40	

Supplies

Requirements

Table 1

In this table, x_{ij} denotes the amount shipped from warehouse i (Wi) to market j (M_j) . These unknowns are constrained by the linear equations:

$$x_{11} + x_{12} + x_{13} = 90$$

$$x_{21} + x_{22} + x_{23} = 70$$

(i.e., the total amount supplies from each warehouse equals the amount available there), and

$$x_{11} + x_{21} = 50$$

$$x_{12} + x_{22} = 70$$

$$x_{13} + x_{23} = 40$$

(i.e., the total amount supplied to each market equals the amount required there), and

$$x_{ij} \geq 0 \ , \quad \text{for } i = 1,2, \quad \text{and} \quad j = 1,2,3,$$

(i.e., only non-negative amounts can be shipped).

The function to be minimized is the linear form expressing the transportation costs:

$$z = 7x_{11} + 5x_{12} + 8x_{13} + 2x_{21} + 3x_{22} + 4x_{23} \ .$$

This linear program, although it is stated in terms of six unknowns, can be reduced by an algebraic device to a problem in two variables for graphical treatment. To see this, let $x = x_{11}$ and $y = x_{12}$ and use four of the warehouse and market equations to express the remaining unknowns in terms of x and y. Precisely:

$$(*) \qquad \begin{aligned} x_{13} &= 90 - x - y \\ x_{21} &= 50 - x \\ x_{22} &= 70 - y \\ x_{23} &= 70 - x_{21} - x_{22} = x + y - 50 \ . \end{aligned}$$

In addition, the inequalities $x_{ij} \geq 0$ yield six inequality constraints on x and y. Precisely:

$$\begin{aligned} x_{11} \geq 0 &\longrightarrow \quad x \geq 0 \\ x_{12} \geq 0 &\longrightarrow \quad y \geq 0 \\ x_{13} \geq 0 &\longrightarrow \quad 90 - x - y \geq 0 \\ x_{21} \geq 0 &\longrightarrow \quad 50 - x \geq 0 \\ x_{22} \geq 0 &\longrightarrow \quad 70 - y \geq 0 \\ x_{23} \geq 0 &\longrightarrow \quad -50 + x + y \geq 0 \ . \end{aligned}$$

The region of the x - y plane defined by these inequalities is shaded in Figure 4. The only shipments that satisfy the requirements of the problem are defined by points (x,y) of this region by setting $x_{11} = x$, $x_{12} = y$ and using equations (*) above to find the other unknowns. (See Figure 4 attached).

The object of the program is to minimize the shipping costs z.
If the cost is expressed in terms of x and y , we obtain:

$$z = 7x + 5y + 8(90 - x - y) + 2(50 - x) + 3(70 - y) + 4(x+y - 50)$$

or

$$z = x - 2y + 830.$$

Since this is a linear function of x and y, the minimum value must occur at one of the "corner-points" of the region shaded in Figure 4. Actually, the shading has been drawn along contour lines of the function (i.e., lines of equal cost) spaced in units of ten and decreasing from A to E. In Figure 5, the portion of the plane surface $z = x - 2y + 830$ above the region of admissible x and y has been graphed. The shading follows lines of equal cost and the corner points on the surface are labeled with the corresponding transportation costs. From either figure, it is clear that the mimimum cost is achieved at the corner-point E ($x = 0$, $y = 70$) and is $z = 690$. (See Figure 5 attached).

Although our success in giving a complete solution to this program by graphical methods is something of an accident, Example 2 illustrates a universal feature of linear programs: The region of admissible values of the variables is always a closed convex polyhedron, i.e., a closed region in space with flat boundaries that contains any line segment joining two points in the region. With one variable, a closed convex polyhedron is simply a closed interval. The shaded region of Figure 4 is a typical bounded polyhedron in two variables. The first shaded region of Figure 6 is an unbounded convex polyhedron, the second region is a polyhedron but is not convex since not all of the line segment joining P to Q is in the set. (See Figure 6 attached).

The second universal fact about linear programs illustrated by Example 2 is that the solutions, if any, are always to be found at corner-points of the admissible region. Thus, in theory, any linear program could be solved by listing the corner-points and calculating the values of the objective function at these points only. The obstacles to this procedure as a practical method should be clear. When the number of variables becomes realistic, the number of corner-points becomes unmanageable (this will be evident in Example 6). Each computation of a corner-point requires the solution of a system of linear equations and, in the absence of special information, it is not even clear which equations should be solved. (Thus, in Figure 4, every corner-point is the solution of two equations in two unknowns. The corner-point D is the solution of $x+y=90$, $y=70$ but it would be tedious to exclude the points obtained from such pairs as $x + y = 50$, $y = 70$ without the graph to guide us). In spite of the pessimistic tone of these remarks, the most successful computational routines operate by computing a sequence of corner-points so as to improve the value of the objective function at each step. To see such a procedure in operation, we will solve Example 2 again.

The solution is begun with a corner-point obtained by the following "common-sence" rule: Ship as much as you can at the least transportation cost, then at the next higher cost, and so on until all requirements are met. Listing the unknowns in the order that they are determined by this rule, this yields:

$$x_{21} = 50 \text{ , } x_{22} = 20 \text{ , } x_{23} = 0 \text{ , } x_{12} = 50, \; x_{11} = 0 \text{ , } x_{13} = 40.$$

Note that this is the corner-point C in Figure 4 ($x = x_{11} = 0$ and $y = x_{12} = 50$) and that the transportation cost $z = \$730$.

To improve this distribution (without using the graphical information previously obtained), it is useful to gauge how close the trial comes to being a solution. This can be done by introducing "accounting prices" to measure the value of the product at the warehouses and markets. These prices will be such that the change in value in transferring a given quantity from warehouse to market will be no greater than the transportation cost. The economic rationale of this restriction should be clear; if accounting prices are set in this manner, the actual shipping costs of any distribution will be not less than the change in the accounting value of the inventory, or as we shall call it, the accounting cost of transportation. This fundamental property is pictured in Figure 7 (at this point, it is in question whether accounting costs and shipping costs are ever equal): (See Figure 7 attached).

Thus, if we are trying to obtain an estimate of the efficiency of a trial distribution, a lower bound is furnished by any accounting cost. To make this estimate as good as possible, accounting prices should be chosen so as to make the accounting cost of transportation as high as possible. In common-sense terms, the change in inventory value should be as close as to actual amount paid out for transportation as possible.

Let the accounting prices be denoted by w_1, w_2 and m_1, m_2, m_3 at the warehouses and markets, respectively. Then the accounting cost is

$$a = 50m_1 + 70m_2 + 40m_3 - 90w_1 - 70w_2 \text{ .}$$

Initial accounting prices can be set by the following rule: Choose the warehouse that would have the highest total transportation cost if the whole requirement could be shipped from there. Set the accounting price at that warehouse at zero and the accounting prices at the markets equal to the transportation costs from that warehouse. Prices at the other warehouses are then set as low as possible. For the example, this yields:

$$w_1 = 0 \text{ , } m_1 = 7 \text{ , } m_2 = 5 \text{ , } m_3 = 8 \text{ , } w_2 = 5 \text{ ,}$$

and $a = \$670$ as accounting cost. We now know that the shipping costs cannot be brought below \$670. How can the gap between \$670 and \$730 be closed? The difference is due entirely to the one shipment of 20

tons from W2 to M2. Here 20 tons are being shipped at $3 cost but with no change in accounting cost. It is reasonable to try to repair this by adjusting the accounting price at M2. If an increase of $1 is tried, it forces the following adjustments.

$$m_2 = 5 + 1,\ w_1 = 0 + 1,\ m_3 = 8 + 1,\ m_1 = 7\ ,\ w_2 = 5.$$

This is the largest shift of this type since any further increase is blocked by the requirement that the change in value from W2 to M3 be not greater than $4 per ton. The new accounting cost is a = $690. There is no obvious way to improve this; the difficulty is still in the same shipment but accounting prices cannot be further altered without involving a chain of forced adjustments that will decrease the accounting cost.

However, there is another way to close the gap between accounting cost and shipping cost. This is to switch the 20 ton shipment from W2 - M2 to W2 - M3. This forces the following adjustments (which are related to the chain that established the impossibility of improving the present accounting prices):

$$x_{22} = 20 - 20,\ x_{12} = 50 + 20,\ x_{13} = 40 - 20,\ x_{23} = 0 + 20,\ x_{11} = 0,\ x_{21} = 50.$$

The shipping cost is now z = $690 and it is certain that this is the lowest possible because it is equal to the accounting cost of the distribution.

While this example is far from being realistic, it does illustrate a point of general theory, the duality theorem of linear programming. Stated informally, it asserts that, for every problem of optimizing a linear function in non-negative variables subject to linear restrictions on the variables, there is a related problem, called the dual program. If the original program is a minimum problem, the dual program is a maximum program. The theorem states that the values of these dually related programs are equal, and the solution to one program can be checked by finding a solution to the other program that equates the values of the two objective functions. Applied to Example 2, a necessary and sufficient condition for an optimum distribution is that there be accounting prices which equalize accounting costs and shipping costs.

The majority of practical applications of linear programming have been transportation problems in one form or another. This is somewhat remarkable, since the theory of the general transportation problem is as simple as Example 2. There are m sources, denoted by i = 1,...,m , and n destinations, denoted by j = 1,...n, and a homogeneous commodity to be transported from the sources to the destinations. Amounts r_i are available at the sources and amounts s_j are required at the destinations, where

$$\sum_{i=1}^{m} r_i = \sum_{j=1}^{n} s_j .$$

The cost of shipping a unit amount of the commodity from source i to destination j is c_{ij}. The problem is to find amounts x_{ij} to ship from each source to each destination so as to minimize the total cost $\sum_{ij} c_{ij} x_{ij}$. The unknowns x_{ij} are restricted to be non-negative and must satisfy the balance equations:

$$\sum_{j=1}^{n} x_{ij} = r_i \qquad (i = 1,\ldots,m)$$

and

$$\sum_{i=1}^{m} x_{ij} = s_j \qquad (j = 1,\ldots,n).$$

The dual program is exactly analogous to that used in the solution of Example 2. It asks for accounting prices at the sources (m_i) and at the destinations (w_j) such that

$$w_j - m_i \leq c_{ij} \qquad (i=1,\ldots,m;\ j=1,\ldots,n)$$

and so as to maximize the accounting cost of the transportation,

$$a = \sum_{j=1}^{n} w_j s_j - \sum_{i=1}^{m} m_i r_i .$$

The next three examples present three actual instances of applications of the transportation model; they are chosen both on the basis of their verisimilitude and by their ingenious interpretations of the model.

EXAMPLE 3. (The Caterer Problem) In connection with meals that he has contracted to serve over a period of n days, a caterer knows that he will need r_j clean napkins on the jth day, $j = 1,2,\ldots,n$. The initial supply of napkins is to be purchased for a cents per napkin. Dirty napkins can be laundered in p days for b cents each or, by a special laundry service, in q days for c cents each, where $q < p$ and $b < c < a$. Arrange a schedule for the caterer that will meet the requirements and minimize the cost for the period of n days.

The Caterer Problem is a paraphrase of the practical military problem of scheduling the purchase and service of spare aircraft engines so as to maintain given operational levels of a fleet of airplanes. As posed above, the problem has a direct interpretation as a Transportation Problem. The product to be distributed is napkins and the sources are the store and each day's supply of dirty napkins. The destinations are the days of the period and the final inventory of dirty napkins. To "ship" a clean napkin from the store to any day costs a cents; from the

store to the final inventory, the cost is infinite. The cost of shipping a napkin from the jth day's supply of dirty napkins to the kth day is b cents (when $k - j \geq p$) or c cents (when $q \leq k - j \leq p$); this cost might be considered infinite when $k - j < q$. Finally, the cost of shipping a napkin from anyday's supply of dirty napkins to the final inventory is zero.

EXAMPLE 4. (Bid Evaluation for Contract Awards) Suppose that a government agency wishes to purchase a homogeneous commodity to be delivered in various amounts to a number of depots. A number of manufacturers are willing to produce various amounts of this item, at stated prices per item at each of the depots. Award contracts so as to satify the requirements at the depots and the conditions of the bidders at a minimum total cost.

As stated, the problem is almost immediately a Transportation Problem. The sources are the bidders; the destinations are the depots. The "shipping costs" will include the cost of government furnished property, the stated price per unit less any discount the manufacturer offers, plus the unit shipping cost from point to point. Notice that, in general, more of the commodity will be offered than is required. This excess can be accounted for by establishing a fictitious depot which absorbs the excess at zero cost from all bidders. This formulation is not realistic since it ignores actual conditions such as hinge bidding, multiprice lots from a single bidder, minimal acceptable quantities, scheduling, and other factors which may affect the answer significantly. However, it is the first step toward a complete statement of the problem.

EXAMPLE 5. (Machine scheduling) A certain company uses several large manufacturing machines, each costing over one million dollars. Each machine operates continuously and carries out four operations in sequence. Each of the operations can be performed in three or four different ways. The machines operate on two kinds of raw materials, with twenty types of the first and forty types of the second raw material available. This large number of combinations makes nearly two and a half million products possible in this industry; of these, only about two thousand are now being produced.

For reasons not connected with linear programming, the company believes that it is an optimal policy to schedule products in groups of one hundred. After a group of one hundred products, there is a general cleanup and a changeover to another group of one hundred products.

Within the group of one hundred products, between fifty and sixty per cent of machine time is taken up by changing from one product to another. Money is lost in paying operating crews, on material that is lost in the adjustment of the machinery, and on material that is lost at the end of the run. The best present estimate of the losses due to changeover in this industry is about a quarter of a million dollars a year. Undoubtedly, a significant fraction of this loss is due to the

fact that the order of products within a group of one hundred is selected by the following fallacious rule-of-thumb: From each product, proceed to the product, as yet unproduced, with the smallest changeover costs.

However, this problem also fits the transportation model if it is thought of in the following manner: The sources are the products and a special "start" source; the destinations are the products and a special "finish" destination. One unit (of the fictitious commodity "production" is available at each source and one unit is required at each destination. The costs are simply the changeover costs. Again, this formulation of the problem ignores an essential feature; the final schedule must list all of the one hundred products in one sequence and "cycles" of fewer products are not acceptable. An adequate treatment of this problem is not available now.

The final illustration of this paper is relevant to the machine scheduling problem and will give some taste of the computational problems that are encountered.

EXAMPLE 6. (A Personnel Assignment Problem) Ten men are available to fill ten jobs. In the matrix of Table 2, each of the ten rows represents a man, and each of the ten columns represents a job. The intersection of the ith row (Mi) and the jth column (Jj) is marked with a 1 if the ith man is qualified for the jth job; otherwise, it is left blank. Each man is to be given one job and each job is to be assigned to one man. The assignment is to be made so as to include the largest number of qualified assignments.

MEN \ JOBS	1	2	3	4	5	6	7	8	9	10
1	1			1		1		1		
2						1				
3					1					
4		1	1		1				1	
5						1				
6		1		1		1			1	1
7			1			1				
8					1		1			
9	1		1				1			
10					1		1			

Table 2

This type of problem is easily recognized as a linear program. To see this, introduce 100 variables x_{ij} to indicate the possible assignment of man i to job j, setting x_{ij} equal to 1 if the assignment is made, and 0 otherwise. The requirement that each man is to be given one job can then be written as

$$(**) \qquad \sum_{j=1}^{10} x_{ij} = 1 \qquad (i = 1,\ldots,10),$$

and since each job is to be assigned to one man,

$$(***) \qquad \sum_{i=1}^{10} x_{ij} = 1 \qquad (j = 1,\ldots,10).$$

To express the qualifications of the men, introduce a 10 by 10 matrix $Q = (q_{ij})$, where q_{ij} equals 1 if man i qualified for job j, and equals 0 otherwise. (The matrix Q is shown in Table 1, if the blanks are filled with zeros.) Then the number of qualified men in an assignment is counted by

$$\sum_{i,j=1}^{10} q_{ij}\, x_{ij},$$

and it is this linear form that we wish to maximize.

There are 3,628,800 (= 10 !) possible ways to assign ten men to ten jobs. In the formulation above, each is represented by assigning a value of 0 or 1 to each x_{ij} so as to satisfy (**) and (***). If we allow the x_{ij} to take on any values between 0 and 1, but still restricted by (**) and (***), we obtain a convex polyhedron (of 81 - dimensions) with the 3,628,800 possible assignments as "corner-points". Since the maximum value of the linear form is certainly achieved on a "corner-point", this does not change the problem in any essential way and we have posed the problem as a linear program.

However, let us ignore this formulation and attempt a solution by another "rule-of-thumb": Assign each man in turn to the first job for which he qualifies and which is not already assigned. This yields the following assignment:

M1 assigned to J1

M2 " " J6

M3 " " J5

M4 " " J2

M6 " " J4

M7 " " J3

M8 " " J7 .

Notice that M5 is not assigned by the rule since the only job for which he is qualified (J6) has been given to M2. For similar reasons, M9 and M10 are not assigned by the rule. For the purposes of the problem, it does not matter how these men are assigned among the three remaining jobs (J8, J9, and J10). The resulting assignment places seven qualified men in jobs. However, there is no assurance that it is optimal since it is but one possibility out of 3,628,800.

It is natural to try to improve the assignment by shifting men from job to job. For example, we can shift M1 to J8, opening J1 for M9. If this is done, we have the new assignment of eight qualified men:

M1 assigned to J8

M2 " " J6

M3 " " J5

M4 " " J2

M6 " " J4

M7 " " J3

M8 " " J7

M9 " " J1 .

This assignment has been recorded on Table 3 by circling the qualified placements.

JOBS

MEN	1	2	3	4	5	6	7	8	9	10
1	1			1		1		(1)		
2						(1)				
3					(1)					
4		(1)	1		1				1	
5						1				
6		1		(1)		1			1	1
7			(1)			1				
8					1		(1)			
9	(1)		1				1			
10					1		1			

Table 3

This improvement is encouraging, so it is reasonable to try another shift. Such a shift must originate with a man who is assigned to a job for which he is qualified, and moves him to a job for which he is qualified, but which is as yet unassigned. Thus the only possible shifts start with M4 or M6. They are enumerated in Table 4 below.

Shift 1 { M4 shifts from J2 to J9; M6 " " J4 " J2; M1 " " J8 " J4 } (frees J8)

Shift 2 { M6 shifts from J4 to J9; M1 " " J8 " J4 } (frees J8)

Shift 3 { M6 shifts from J4 to J10; M1 " " J8 " J4 } (frees J8)

Table 4

Thus, each of the possible shifts results merely in freeing a job (j8) for which no unassigned man is qualified. The remarkable fact is that this impossibility of an improvement by means of shifting assignments provides us with a proof that the last assignment was optimal. To see this, define a mobile man (relative to the given assignment) as any

assigned man who appears in one of the shifts enumerated above (thus, M1, M4, and M6 are mobile). Further, define a stable job (relative to the given assignment) as any assigned job that does not figure in one of the shifts enumerated above (thus, J1, J3, J5, J6, and J7 are stable). In Table 5, the rows of mobile men and the columns of stable jobs are shaded.

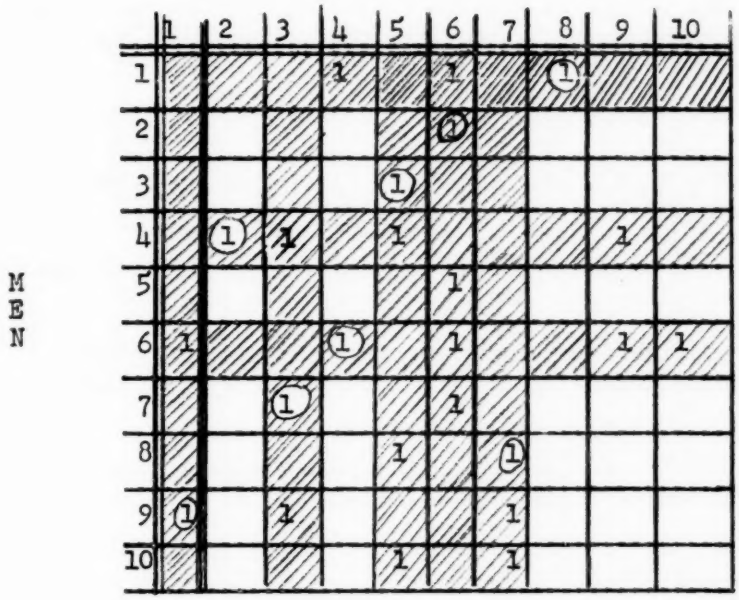

Table 5

There are eight such lines (rows or columns) and between them they contain all of the 1's in the matrix. This proves that the last assignment of eight qualified men was optimal since any assignment of more qualified men would pick two 1's from a shaded row (one man assigned to two jobs) or two 1's from a shaded column (two men assigned to one job).

It should be clear that the Assignment Problem is but another Transportation Problem and that the solution again illustrates the duality theorem. Details are left to the reader.

HISTORICAL REMARKS. For a reader who wishes a more complete treatment of the mathematical theory of linear programming, References [1], [2], [3], and [4] may prove useful. They are arranged in increasing order of mathematical sophistication. References [1] and [2] are connected accounts and emphasize the computational algorithm known as the Simplex Method. References [3] and [4] are collections of basic research papers. A comprehensive bibliography of over 250 items is contained in [4].

The algorithm used in this paper to solve the Transportation Problem is due to the L.R. Ford, Jr. and D. R. Fulkerson /5/. It is a generalization of the author's Hungarian Method for the Assignment Problem /6/, which was used in the solution of Example 6. The Caterer's Problem was originally posed by W. W. Jacobs /7/; a subsequent treatment appeared in /8/. The suggestion that it can be interpreted as a Transportation Problem stems from William Prager /9/. The problem of bid evaluations is treated in /10/. The source of Example 5 is confidential due to the competitive nature of the industry. However, similar problems are treated by Flood in /11/.

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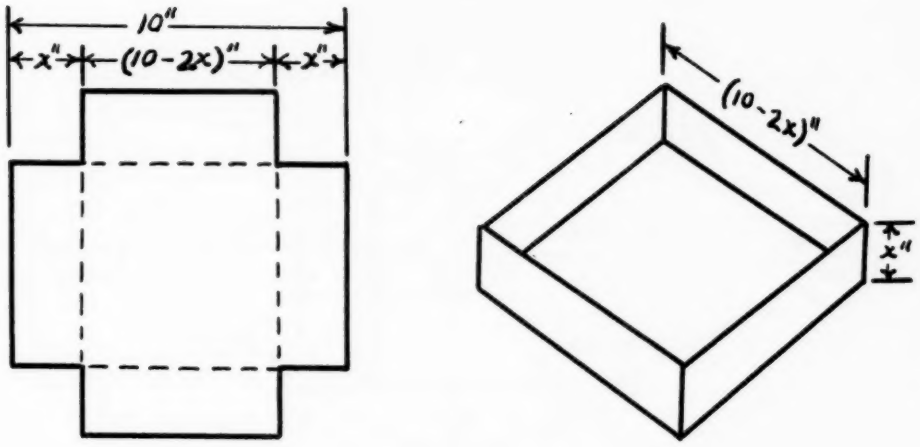

Figure 1

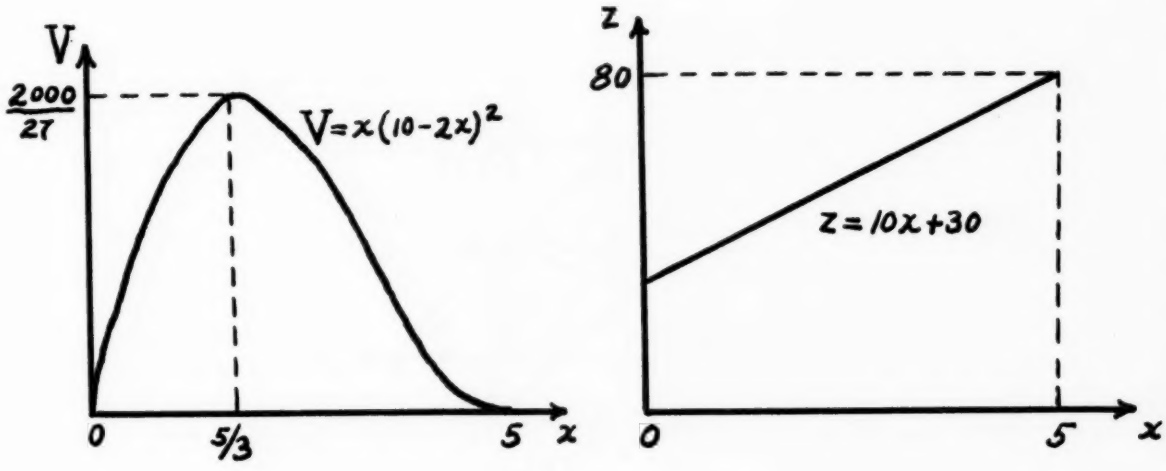

Figure 2

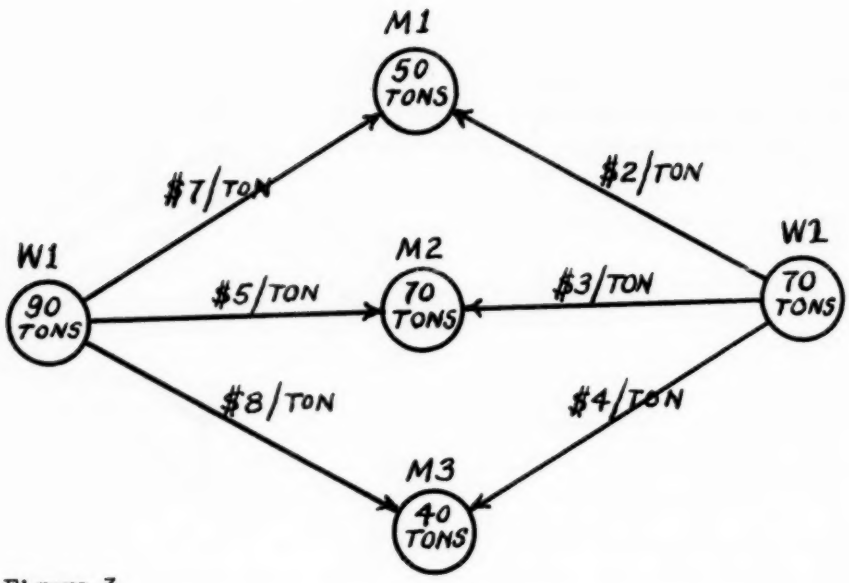

Figure 3

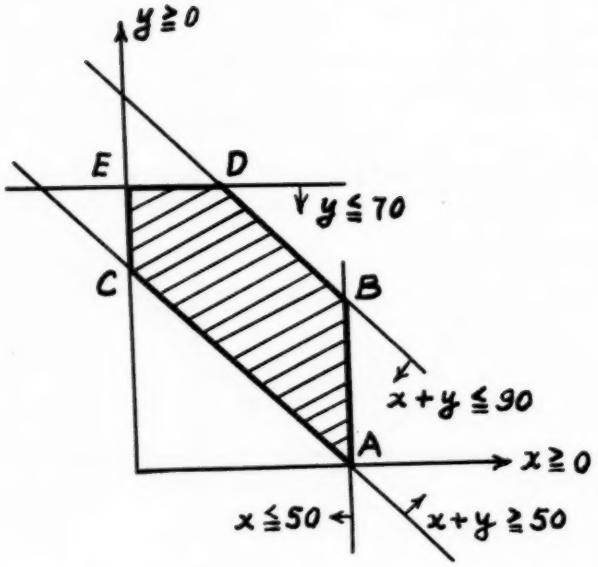

Figure 4

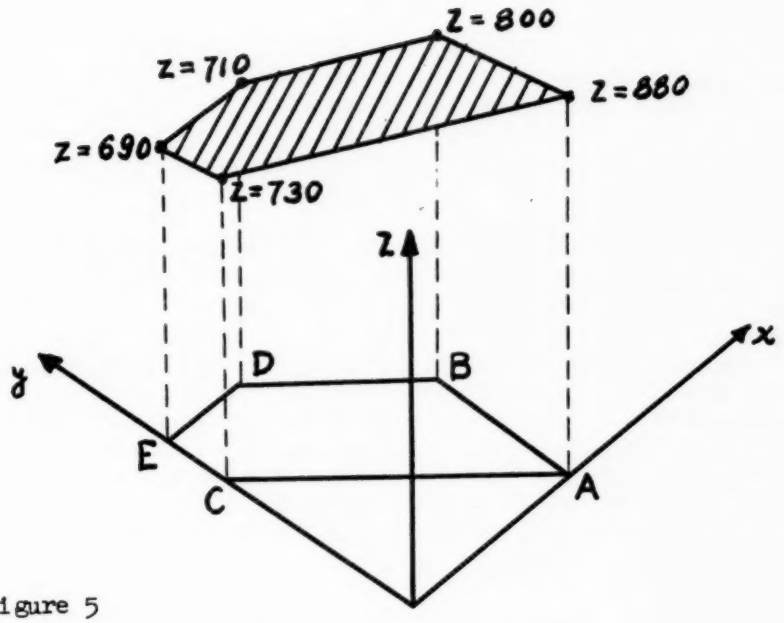

Figure 5

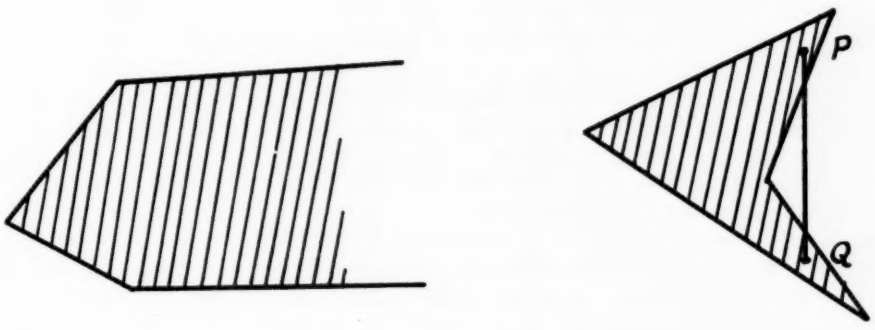

Figure 6

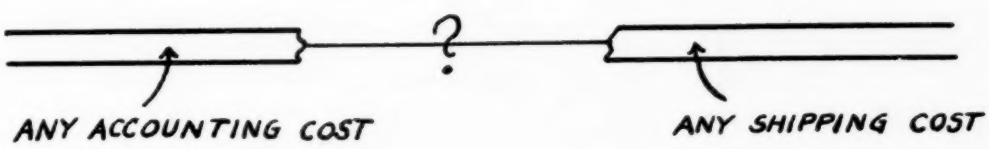

Figure 7

THE DEVELOPMENT OF MANAGEMENT CONTROLS

Dr. Irwin P. Lazarus
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I imagine most of you are a part of large organizations. I also represent a large organization, of about 130,000 employees and ninety-five different plants. I am sure our top management has one problem in common with your top management. That is, a feeling of not truly understanding how well we are progressing in all phases of the organization. To give top management the tools with which it constantly can feel the pulse of overall operations is the responsibility of the Industrial Engineer. We call these tools "management controls" and I should like to describe how we developed a set of them for our particular situation.

Sometime ago the Deputy Chief of Ordnance (Maj. Gen. E. S. Gruver, A-US, Ret.) requested that our organization develop a system of management controls to give him greater insight into the operations of each of the Ordnance installations in the Commodity Command and Arsenal system. As a central consulting and training group to Defense Department agencies the Ordnance Management Engineering Training Program has often been asked to perform such tasks. He wanted to be able to tell, at a glance, which installations were performing in a superior manner and which were deficient in certain areas of operating management. He wanted a system which would not be merely a historical record, but one which could predict trends and indicate future trouble far in advance of occurence. The system was also required to indicate out-of-control situations and even to predict such out-of-control happenings. In all cases, the control limits were to be used as action lines or the point at which top management must rectify an abnormal situation.

As can be seen on slide #1, it is felt that any system of management controls must cover the following four areas:

1. Manpower
2. Funds
3. Workload and End Item
4. Performance

In our particular case all reporting channels were keyed to the Primary Programs of the Army in order to make this

system compatable with the over-riding reporting system. Number 3, the production area was divided into workload and end item to reflect the productive effort in both government and contractor plants. Workload was defined as all man hours in government operated plants, whereas end item was called the sum total of production in both government and contractor operated plants. The types of charts that illustrate each of the control areas are listed in the body of slide #1.

Lead Time Charting:

Let us first look at the control technique used to measure production effectiveness. The technique has been called the line of balance chart, but we call it simply Lead-Time Charting since it is so dependent upon production lead times for its development. This approach has already been used at Good Year Tire and Rubber, General Electric, American Machine and Foundry, the Navy, Army and many other private and government organizations.

Lead-Time Charting is applicable in any production situation where there is an interrelationship time-wise between assembled components that go into the finished product.

An example of Lead-Time Charting appears in slide #2 and it can be seen that the chart is made up of three parts:

1. A history of lead times appear at the bottom of the chart.

2. The production schedule at the upper left of the chart.

3. The major control chart consisting of the line of balance with actual production on top of it, plotted in the upper right hand corner of the chart.

To build such a chart we must know what components are needed and how many months prior to assembly they must be in the plant ready for processing. On the example chart we can see that forgings, castings, and extrusions must be in the plant five months prior to acceptance. This is denoted by the #1 on the Lead-Time Chart. Item #2, a certain class of raw materials, must be in the plant three and one half months prior to acceptance. And in this fashion, lead times for all components are charted.

In the upper left hand corner, the production schedule is graphed. The production schedule consists of simply the number of completed guns expected by the end of each month. This graph is drawn cumulatively and rises to nearly 450 guns in the total production schedule.

The first two charts are used together to draw the third chart (at the upper right hand corner.) Let us assume that the 1st of March is "Today" and we wish to know how many of each component we should have available in order to complete the total 450 gun schedule. We can determine this for each component in the following manner:

For item #1, the forgings, we see from our Lead-Time Chart that five months are required. By starting from 1 March and moving across five months to 1 August and then moving vertically up to the production schedule we see that it strikes the schedule at 320 forgings. For item #2, a category of raw material we see from the bottom chart that a three and a half months lead-time is required. Moving from the "Today" line of 1 March three and a half months to the right brings us to the middle of June and by moving vertically up to the schedule line from this point, it is apparent that approximately 165 of these components are necessary. In this way the number of components needed for each category of material is determined and plotted on the upper right-hand chart as a horizontal line above the item number. All of these horizontal lines form a staircase that is known as the line of balance.

Actual production as of 1 March is plotted on the upper right-hand chart from production control reports. These appear as vertical bars superimposed on the line of balance. It can be seen that some of the bars are below their required level and some are above the required level. Top Management is normally most interested in the items at the end of the production line, namely those items such as #19, indicating accepted product. It can be seen that item #19, acceptance, is ahead of schedule. Likewise, item #18, tested weapons, is ahead of schedule and #17 and #16, items going into final assembly, are also ahead of schedule. This would appear to indicate to top management that all is going well with the particular item being produced. At least that is the impression seen from looking at completion reports only. However, the control chart of bars that was drawn indicates that some of the components are not present in sufficient quantity to complete assembly on schedule. One of these components, #8, Government Furnished Equipment, appears to be considerably behind schedule. If a horizontal line is

drawn from the top of the bar at #8 to the schedule at the left, it strikes the schedule at a point above the middle of March. This is two weeks in advance of the "Today" line. This indicates that there are two weeks remaining or two weeks lead time for item #8. By checking into the lead-time chart at the bottom, it appears that item #8 requires two months (or 8 weeks) of lead time prior to acceptance. Thus, we have only two weeks of item #8 available and are six weeks behind schedule as far as item #8 is concerned. Of more importance, assuming we don't get another shipment of item #8 at the plant, we will have to close the production line in only two weeks. This is the type of warning of lagging component production that this particular control chart renders so excellently. No other control appears to predict production problem areas as well as lead time charting or to indicate the relative importance of the various components in the item. Using this technique it has been possible for the Navy to allocate components to the particular contractors in the greatest need of those items.[1]

Manpower Controls:

The next area of control to be discussed is that of manpower, an area of vital concern to top management. The first example, shown on slide #3, is a statistical control chart of actual versus authorized personnel levels at one installation. (Along the horizontal axis are plotted three fiscal years and along the vertical axis are plotted the percent deviations of actual from authorized strength levels. These can be computed by finding the difference between actual versus authorized strength and dividing by the authorized strength for the plant at any time.) It can be seen that the authorized personnel level appears as a zero deviation on the chart. Two standard deviations below the average, a lower control limit has been drawn to indicate the limit of normal fluctuation. The upper control limit has been chosen as the authorized level. Between these two lines appears a band of normality and outside of these two lines we may assume that something has occured which would not normally be expectable. Since cases would fall, 95 times out of 100, within the control limits, we may assume that anything outside is a rare occurence and is probably not due to chance.

---

[1] Vice Admiral M. L. Royar, SC, USN, "Navy-Industry Production Analysis Team Work Promotes National Defense", Armed Forces Management, November 1955, p. 5.

It can be seen that the number of personnel at this installation remain within the control limits for all points during the three fiscal years except two. The first of these occurs in November of 1952 when a slight reduction in force dropped the level below the control limit. The next point is in November of 1953 when a large group of people were transferred from the 2nd Army to this installation. If top management at central headquarters had dictated both of these personnel changes, then no action would be forthcoming from Headquarters. However, if such a graph went out of control for no apparent reason, it could well indicate that management at the installation was negligent of its manpower control.

The next chart, slide #4, represents turnover rates at an installation. Again, dates appear along the horizontal and percent of separation along the vertical. (The ordinate value is determined by dividing the monthly loss or gain by the average monthly work force.) A standard line has been drawn to represent the average turnover rate for all of the installations in the system for a three fiscal year period. An upper control limit has been drawn two standard deviations above this average and between this upper control limit and the zero line, 95% of all possible cases, should fall. If a point falls outside of the upper control limit we may assume that it is a rare occurence and that it is due to some external cause, not chance. The turnover within the installation remains almost constant until the middle of 1953 when it can be seen that harmonics start to set in, warning of a more erratic control situation. Finally turnover goes out of control in June of 1954 and it almost can be predicted by drawing a straight line through the tops of the turnover level bars. If this out of control action had not been caused by top management, then it would indicate that an investigation should be made to determine the cause of such an abnormal occurence. In this way, the charts indicate when management action must be taken in order to bring the system back into control.

In like fashion, many other types of charts may be drawn up to indicate personnel or manpower statistics. Control limits may be placed around a graph of manhours divided by produced units to indicate when we are utilizing excessive personnel, as an example.

Financial Controls:

The third control area under investigation is the highly significant area of funds and fiscal actions. In addition to the Profit and Loss Statement and the Balance Sheet, the following fiscal control is recommended.

In slide #5 is shown the typical historical graph of fiscal actions. (Along the base line the four quarters of the fiscal year are shown and along the ordinate the billions of dollars in the funding program are shown.) The top line of the chart indicates the funds allocated to our headquarters in the entire funding program. The next line indicates the funds allotted from our headquarters to the plant in question. The third line indicates the funds obligated on a contract, This particular program happens to be for research and development. The bottom line indicates expended funds or monies paid out in return for value received. It is obvious that the funds cannot be allotted to the installation until they are received by headquarters and that they cannot be obligated out on a contract until they are received by the installation. This is shown by the vertical gap from one fiscal action to the next. The questions arise, however, as to whether the gaps are too large, too small, how should one interpret them and what do they mean. It is felt that this type of presentation can be greatly improved to the added knowledge of top management.

In slide #6 we see the proposed fiscal control which is an application of the previously mentioned Lead Time Charting, only modified for funds.

Again, dates appear along the base line but instead of dollars along the vertical axis, now percent of the funding program is shown from 0 to 100. This allows for a more direct comparison between different installations. The dark line, numbered "4", is the schedule of obligations, an important fiscal action. The line labeled "5" represents the schedule of expended funds and it can be seen that it rises to only a third of the total program since these were three years funds or expendable in a full 36 months. The dotted line at the left of the chart indicates actual obligations and the dark vertical line intersecting the dotted line indicates the "Today" line or the time the chart was made out. The dotted line at the bottom of the expenditure line indicates actual expenditures.

It can be seen from the actual obligations dotted line that obligations are behind schedule. In other words, not enough contracts have been signed. From the intersection of the schedule of obligations and the vertical "Today" line we see that the program should be about 58% obligated. The actual obligations rise only as high as 42%. Therefore, it appears that the program is 16% behind according to the schedule of obligations. By drawing a horizontal line to the left from the point where

"Today" intersects actual obligations, we see that the scheduled obligations are intersected just before November. This means that the program is slightly more than one month behind schedule in obligations. Also, by moving the "Today" line one month in advance, we see that it intersects the schedule of obligations at about 62%. This means that in order to get back on schedule we will have to obligate from 42% to 62% in 30 days or that 20% of the total program must be obligated in the next 30 days. Thus, the Lead Time Control Chart of funds indicates three things:

1. The percent of the total budget program that the installation is either ahead of or behind schedule.

2. The number of months ahead of or behind schedule.

3. The amount of the program which must be made up in the next month in order to get back on schedule.

Although it can be seen that actual expenditures reach only to about 2% whereas scheduled expenditures should be at 10%, this lag is not highly critical since there are 36 months in which to expend all funds.

From the bottom of the chart it can be seen from the Lead Time figures in months just when the various fiscal actions should occur. By moving forward or backward in time from the obligation date a schedule of allocations, allotments and authorizations may be built. From the particular chart in question it can be seen that all allocations, allotments and authorizations are either ahead of schedule or on schedule for the plant in question.

Another example of the same technique may be seen on slide #7, which is offered only because it differs so greatly from the previous slide. On this chart we see that actual obligations intersect the "Today" line at the same point that scheduled obligations meet it. Also, actual expenditures intersect at the proper point. We may therefore conclude that, as of today, all obligations and expenditures are right on schedule for the installation in question. However, a skilled analyst will notice that at this point of the year, December, the program is only 10% obligated. By moving the "Today" line 60 days in the future, it can be seen that obligations rise to nearly 60%. Thus, in two months there must be 50% of the funding program obligated. Therefore, the analyst who will maintain these data must be extremely watchful in the next 60 days to see that all fiscal actions are performed on schedule.

There is also at this installation a tremendous administrative lead in the two months around the 1st of the year and such a method of operating is open to question. From February through April it can be seen that obligations rise only 10%, so this is an extremely slow period in fiscal actions. From beginning May through June, 30% of the total fiscal program is performed and in the last month 20% of the year's program is obligated.

Such a chart indicates that perhaps a complete investigation should be made of the rate of spending at this installation to put the schedule at a more nearly optimum rate.

Slide #8 is an indication of each individual installation's ability to obligate its funds as it had budgeted or scheduled. At the bottom of the slide a bar graph is drawn in percent of the total program for each installation in the system. Lines are drawn to represent the first, second and third quarter budget positions. The black bars are drawn to indicate actual obligations. These black bars are drawn after the close of the first period. Hence, all levels should be above the first quarter line. Thus, it shows that some installations are not obligating the funds as scheduled and are not meeting the planned budget. Such an approach causes erratic scheduling toward the close of the fiscal year and hence must be brought under control. At the top of the chart is a pie graph to illustrate the relative importance of each installation under question. Thus, it can be seen that Redstone Arsenal, controlling roughly half of the total funds for research and development (46%), must be very carefully controlled. From the bottom graph an investigation appears warranted since all funds were not obligated as scheduled. A phone call determined that major contracts were in the process of being signed momentarily and that the funds were as good as obligated, hence, this problem was easily solved. In like fashion, investigations are made to determine causes for missing the schedule for each installation that appears to so warrant. Only then may the bulk of the funds be kept under close control, budget-wise. It must be remembered that the above controls are to be used as an adjunct to the Profit and Loss Statement and Balance Sheet normally prepared by all firms. The Army has gone to a similar approach by means of its industrial funding technique.

Management Controls in Research and Development:

One of the most difficult areas in which to apply management controls has been the area of research and development projects. Progress in these areas are most difficult to gage

and control. In slide #9 is shown the basis for building a system of controls for research and development projects. This is the man-month estimate (by phases) of personnel needed for a research project. The man-month estimate is made by the scientists and engineers in charge of the project or anyone else who has the greatest knowledge concerning the needs of each phase. The graph is drawn up by the research personnel and that represents the greatest amount of paperwork that they are asked to perform. Next, as shown on slide #10, the Control Staff of analysts (which reports to R&D) totals up the man-months for each phase onto a cumulated man-month estimate. Also the total cumulative man-months for all phases are drawn above as the total line.

At the close of each month, photostats of the original estimate are sent to the research personnel and they are asked to sketch right onto the estimate the actual number of people used on the project. This is done by drawing a vertical bar, representing the number of men used. As shown on slide #11, these bars can be converted to actual cumulative lines for each phase. Also the actual total line is drawn and compared to the estimated line. As shown on slide #11, phases 1, 2 and 3 are all running over the man-month estimates. The total man-months are also over the estimate but appears to be coming back toward that estimate. The most significant fact about the chart is that phases 4 and 5 did not start when scheduled and are now three months behind.

By multiplying the total cumulative man-months by the average monthly salary and adding in overhead charges an expenditure schedule may be drawn as shown in slide #12. To the right of slide #12, the expenditure schedule has been converted from dollars to percent, and the percents marked off in 10% increments. This serves as a fiscal control for the complete R & D project.

On slide #13 the actual expenditures are drawn over the fiscal schedule of expenditures. These actual expenditures are derived from the monthly tabulations of project cost from the electric accounting machinery summaries.

In order to make the comparison of actual versus scheduled expenditures somewhat easier, a bar graph has been drawn to the right of the line graph for each project phase. Comparison of the scheduled expenditures with the actual expenditures for each phase indicates which phases are over the budget. Also, phases 4 and 5 show no actual cost,

hence, they did not start on schedule. The total bar graph indicates rate of spending according to each monthly check point. In which month the project fell behind schedule can be seen clearly and also in which month it began catching up appears by comparing the monthly lines.

On slide #14 we have an indication of statistical forecasting, in this case, applied to workload. By cumulating the data for the previous fiscal year and determining the control limits about that cumulative data, a control chart can be drawn for the next fiscal year. The best estimate of business for the next fiscal year was 15 million tons. As the next year began the tonnage was plotted cumulatively. The first point fell somewhat below the estimate. The second point also fell below and by drawing a line through these two points, it could be seen that the fourth month would go out of control. This actually occurred and each succeeding month stayed right on schedule to indicate a cumulative total of 11 million tons. This type of statistical control produces amazingly accurate results because the error is decreased to a minimum by cumulating each monthly figure to the previous month's total.

This type of forecasting chart can be applied to cost control by project. When the cost starts to rise beyond the control limit, action can be taken to either bring them back into line or secure more funds for the budget. In the forecasting of sales this particular chart has proved invaluable and the article by Frances B. Newman of the General Electric Company, entitled, "Better Production Planning from Controlled Sales Forecast" Factory Management and Maintenance, Volume 110, Nr. 6, June 1952, p. 108, is highly recommended. These charts are very similar to typical quality control charts except that the data has been cumulated prior to drawing the control limits. Typical quality control charts are also recommended for management's knowledge of quality levels.

Summary:

Each of the management controls present knowledge of what is supposed to happen, what is actually happening, and what management action is needed to rectify any deficiency. Furthermore these controls tend to:

1. Indicate exceptional performance, both superior and inferior.

2. Indicate trends or predict future situations.

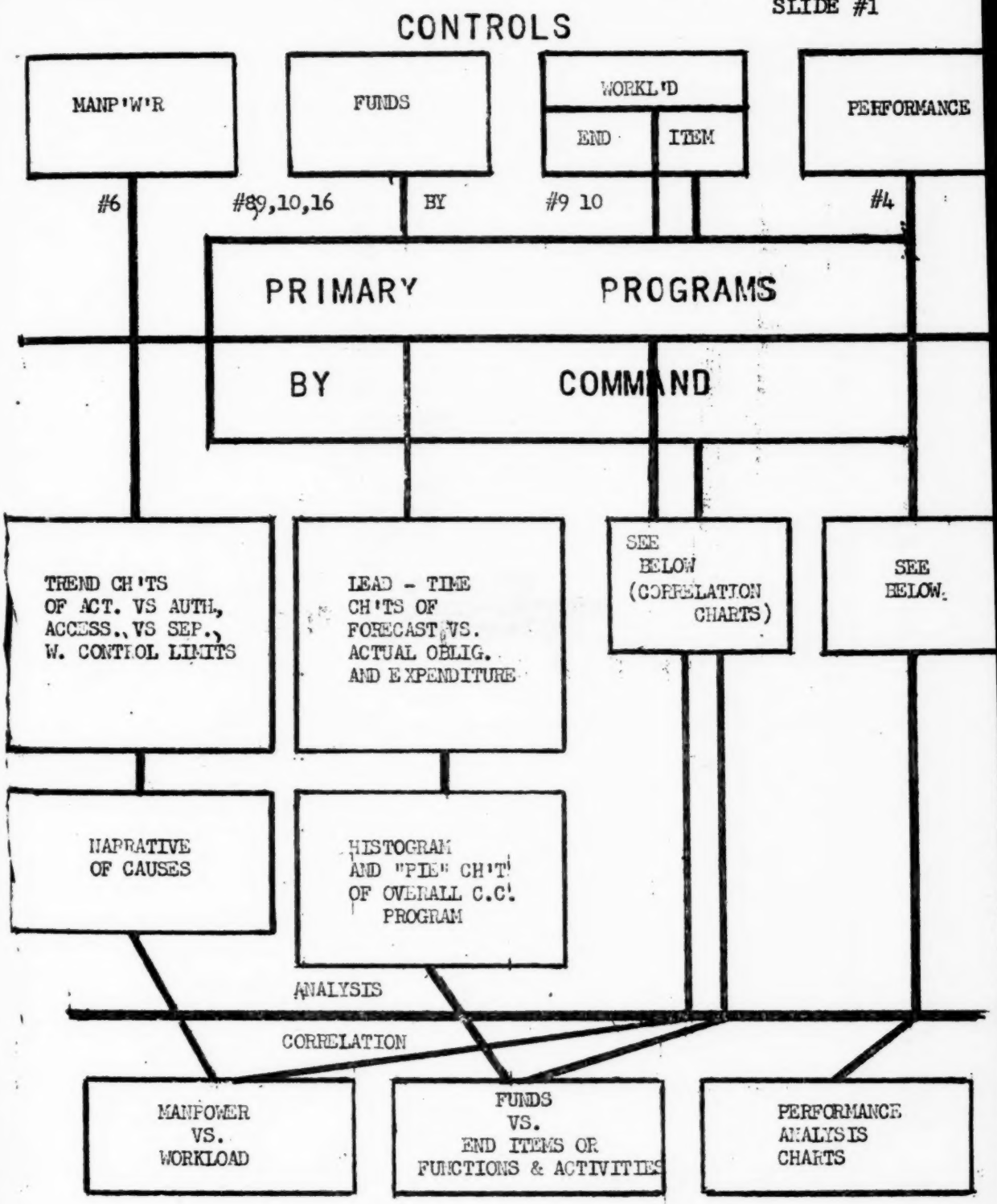
3. Indicate out-of-control situations or predict such out-of-control happendings.

4. Serve not as a historical record but as a warning when to take action.

5. Provide for management by exception.

It is felt that in any large organization, application of some of these controls would be beneficial to top management in providing a quick, clear picture of actual happenings.

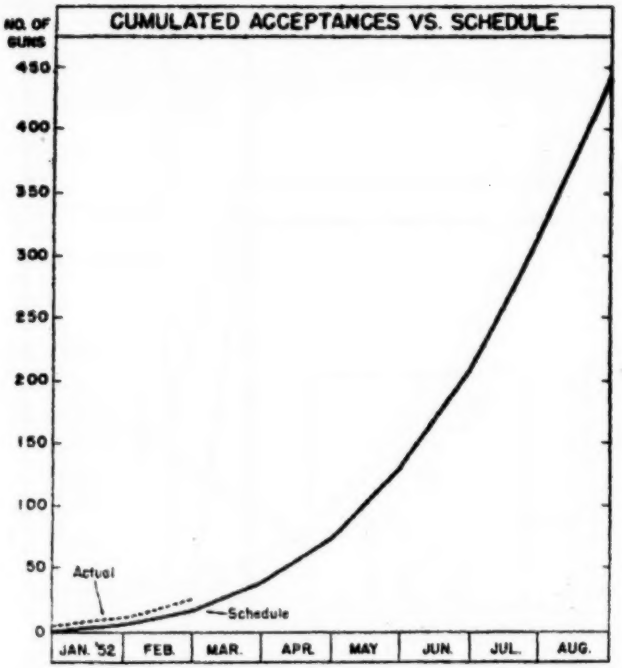
SLIDE #1

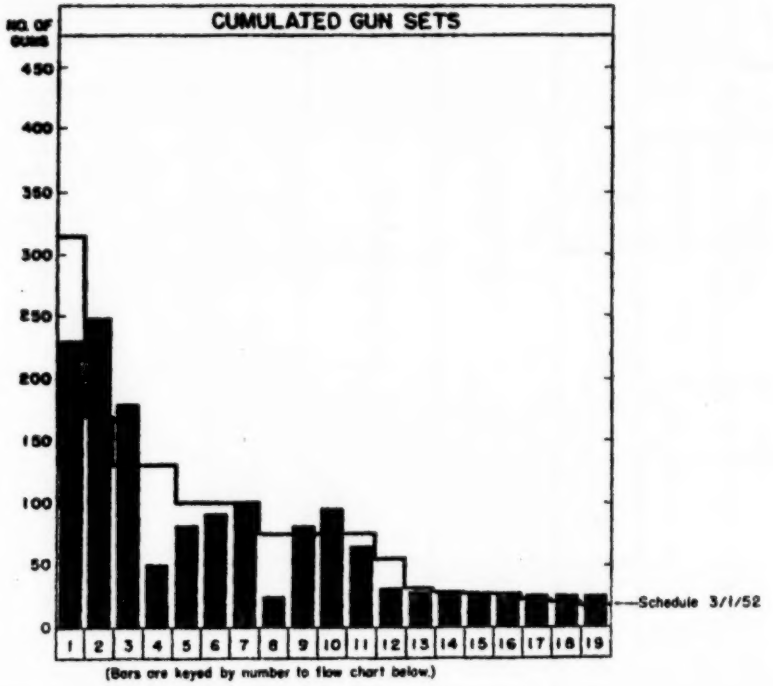

CONTROLS
MANP'W'R
FUNDS
WORKL'D
END
ITEM
PERFORMANCE
#6
#8,9,10,16
BY
#9 10
#4
PRIMARY PROGRAMS
BY COMMAND
TREND CH'TS OF ACT. VS AUTH., ACCESS., VS SEP., W. CONTROL LIMITS
LEAD - TIME CH'TS OF FORECAST VS. ACTUAL OBLIG. AND EXPENDITURE
SEE BELOW (CORRELATION CHARTS)
SEE BELOW.
NARRATIVE OF CAUSES
HISTOGRAM AND "PIE" CH'T OF OVERALL C.C. PROGRAM
ANALYSIS
CORRELATION
MANPOWER VS. WORKLOAD
FUNDS VS. END ITEMS OR FUNCTIONS & ACTIVITIES
PERFORMANCE ANALYSIS CHARTS

CONTRACTS:

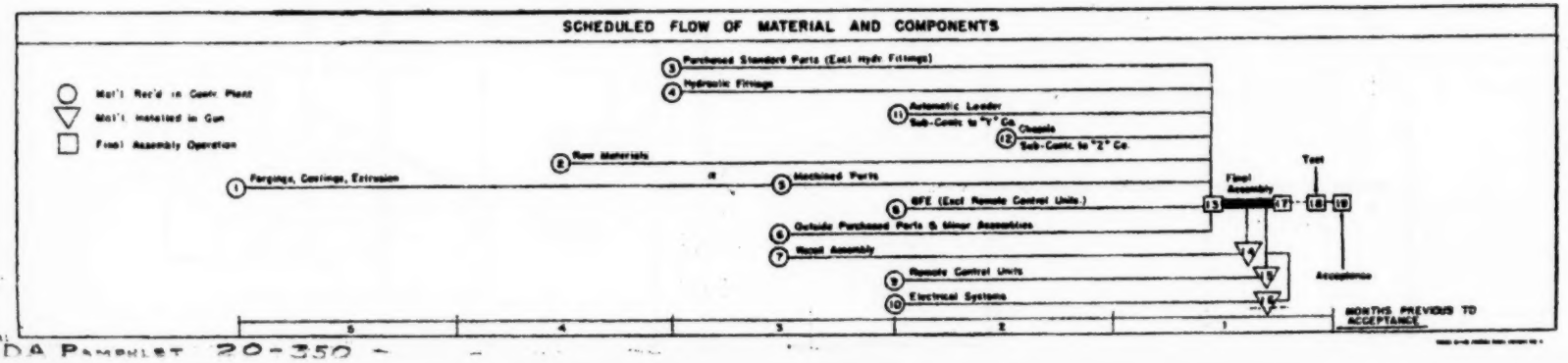
GUN, ANTIAIRCRAFT
X MFG. CORP.
10 JAN. 1952

GUN, ANTIAIRCRAFT, PRODUCTION AND MATERIAL STATUS





(Bars are keyed by number to flow chart below.)



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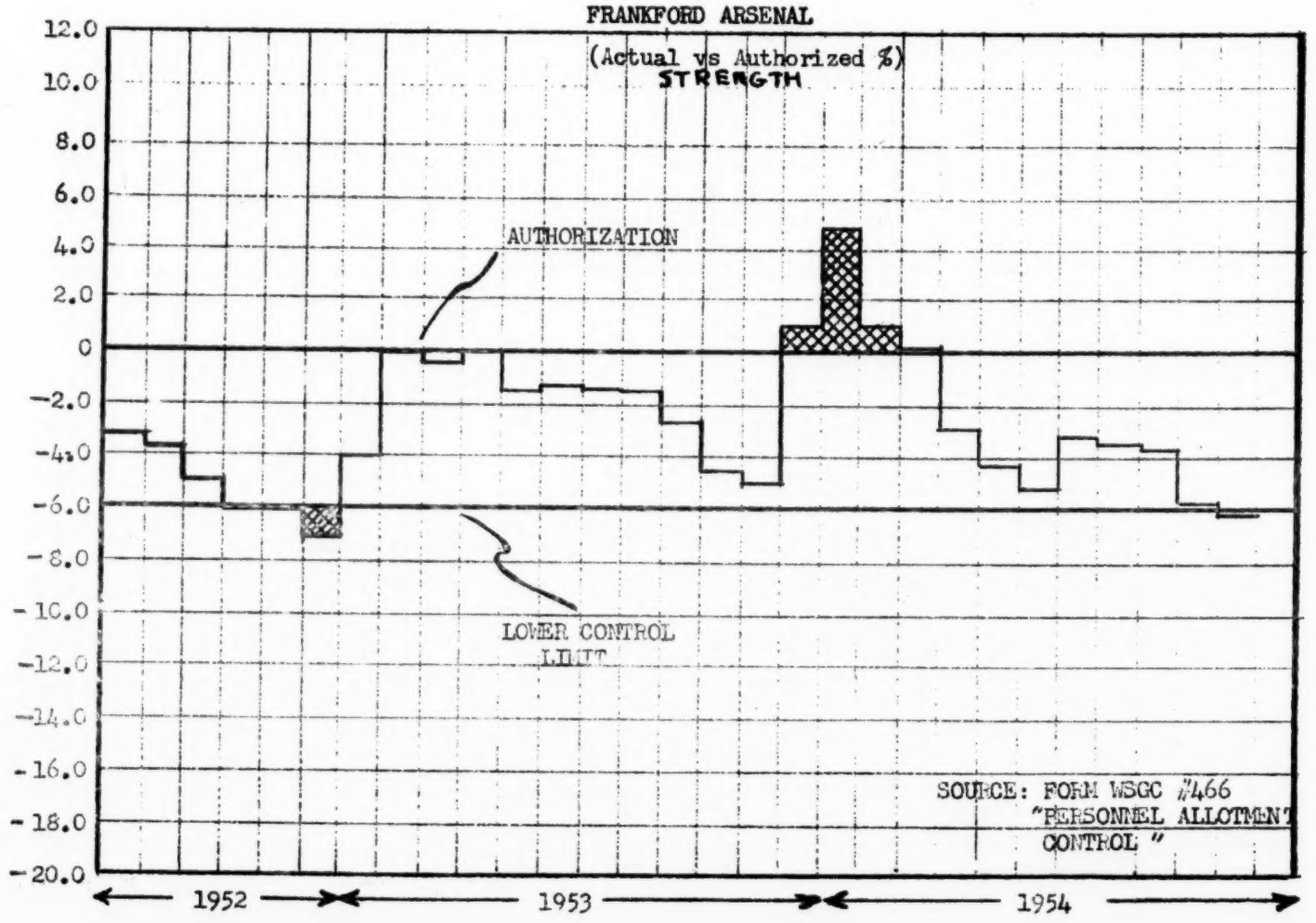
19-13

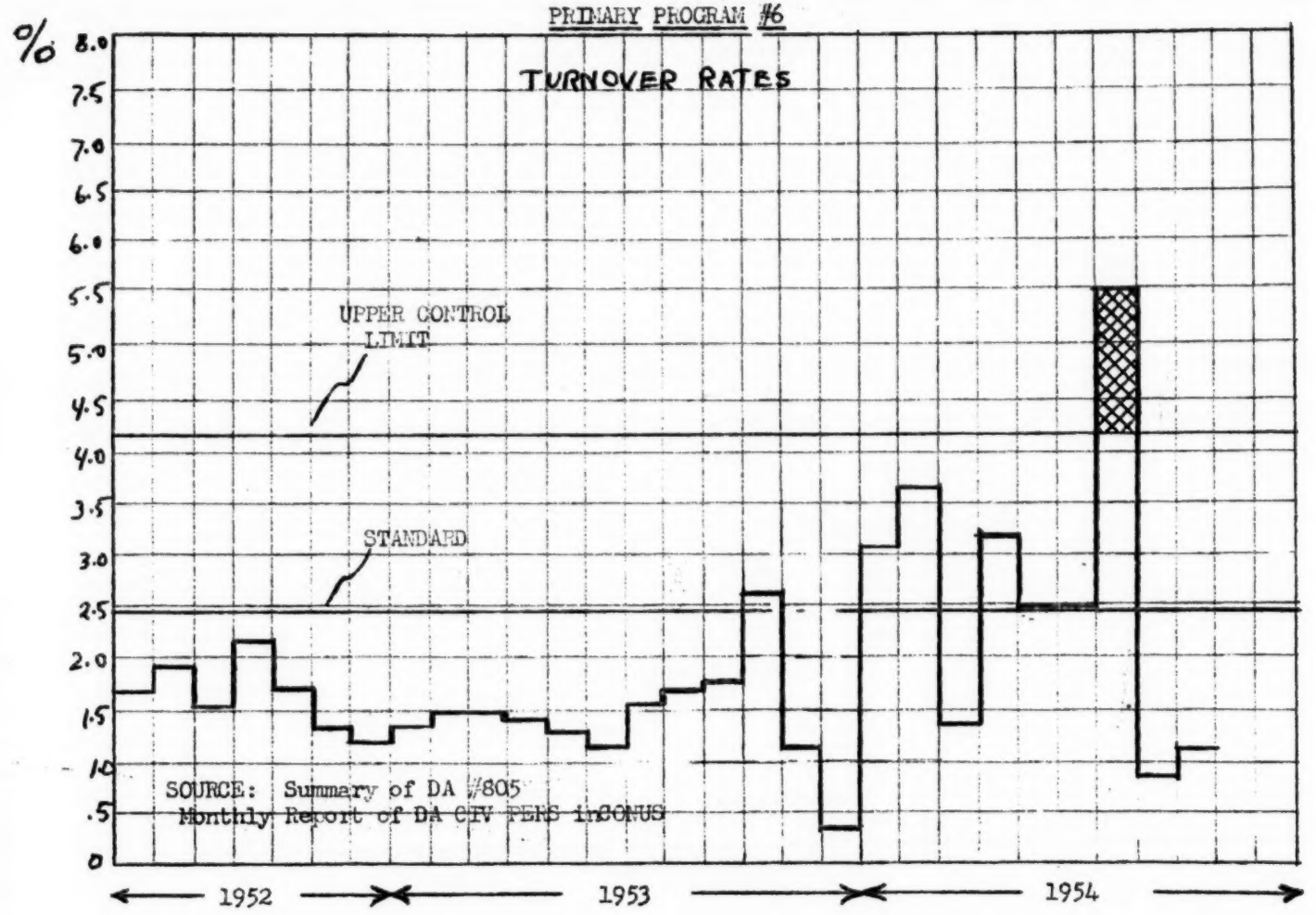
SLIDE #2

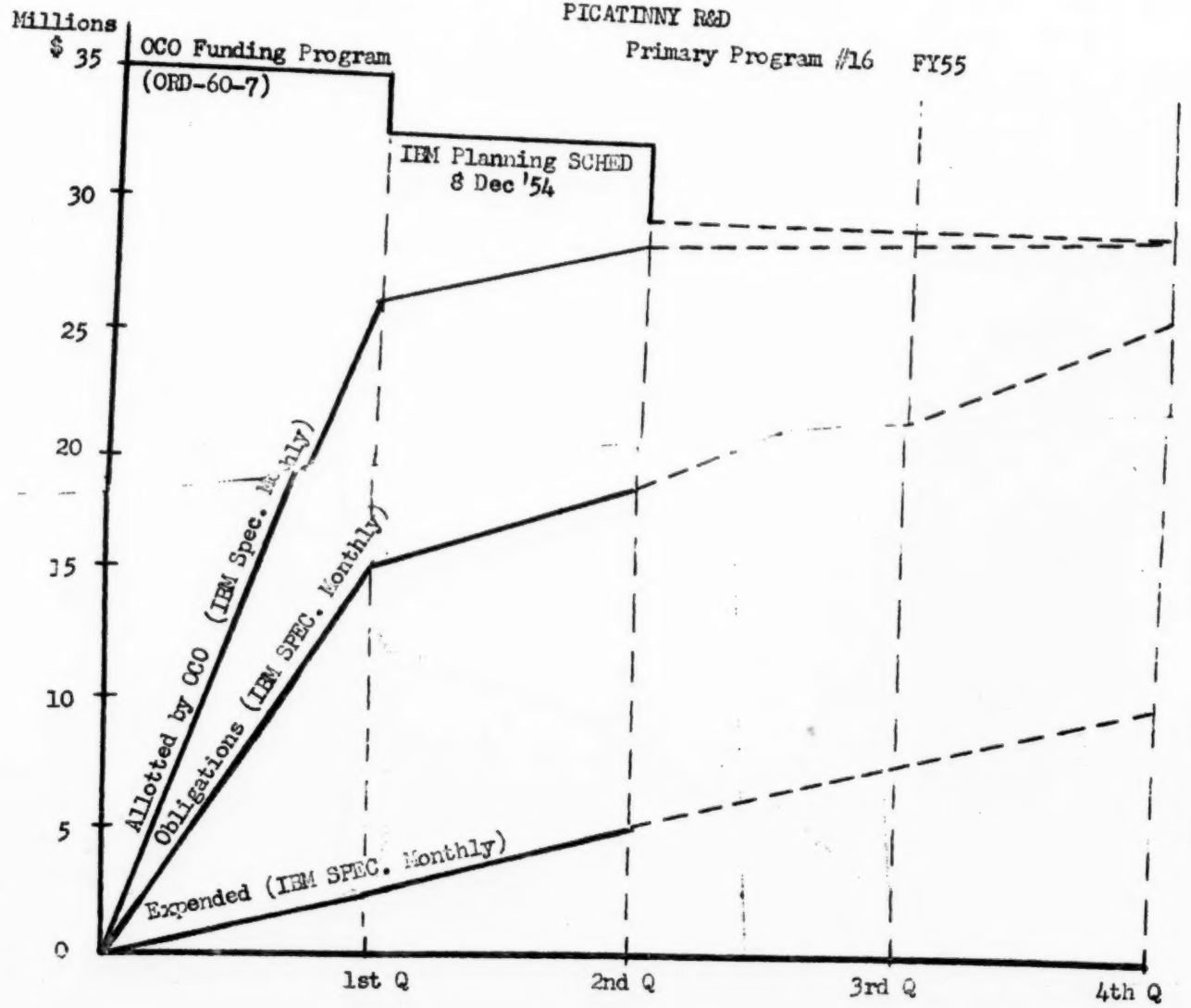
FROM: DA PAMPHLET 20-350 -



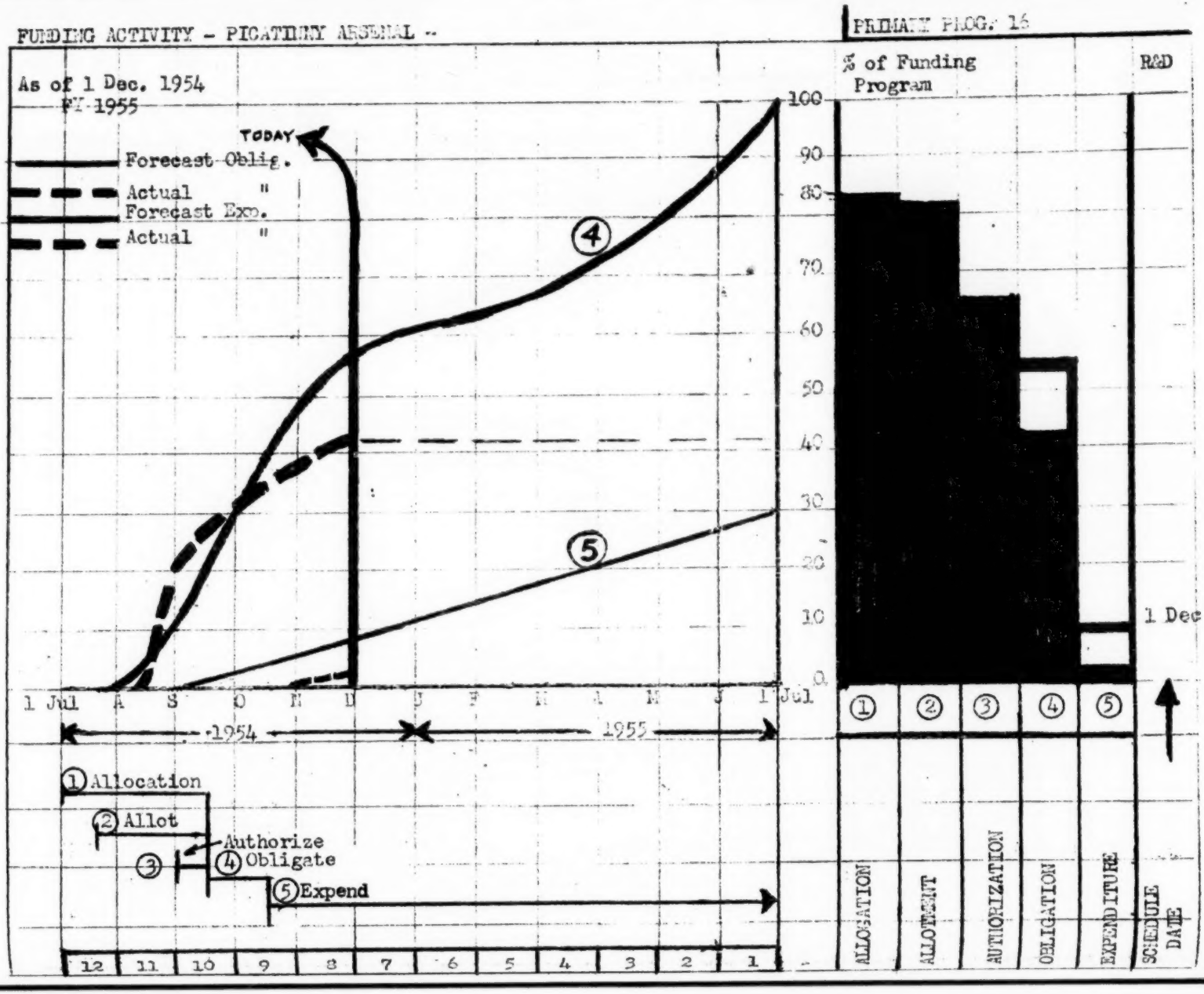
SLIDE #3

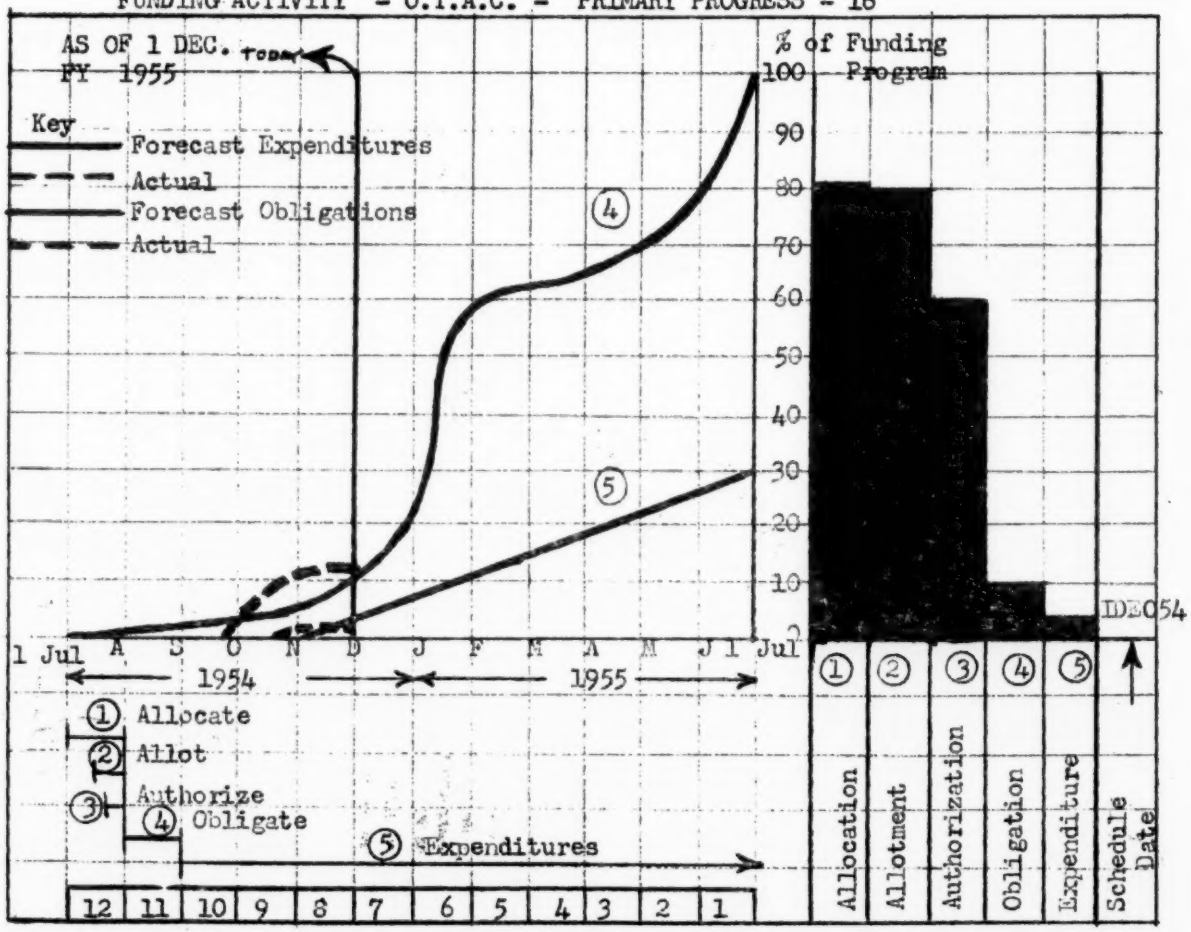
PRIMARY PROGRAM #6




PICATINNY R&D
Primary Program #16 FY55
Millions
$ 35
30
25
20
15
10
5
0
OCO Funding Program
(ORD-60-7)
IBM Planning SCHED
8 Dec '54
Allotted by OCO (IBM Spec. Monthly)
Obligations (IBM SPEC. Monthly)
Expended (IBM SPEC. Monthly)
1st Q
2nd Q
3rd Q
4th Q
FY 55

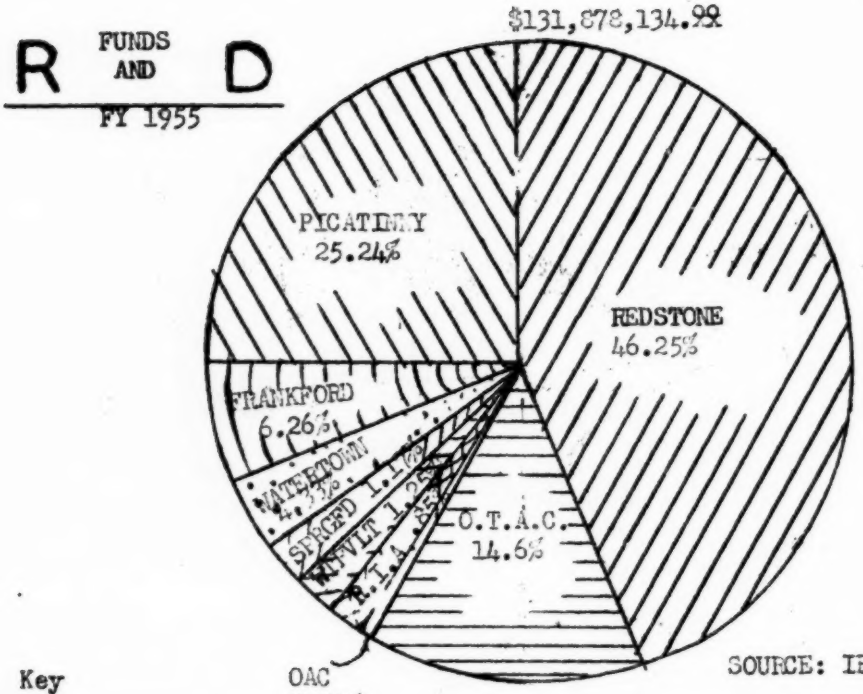
SLIDE #5

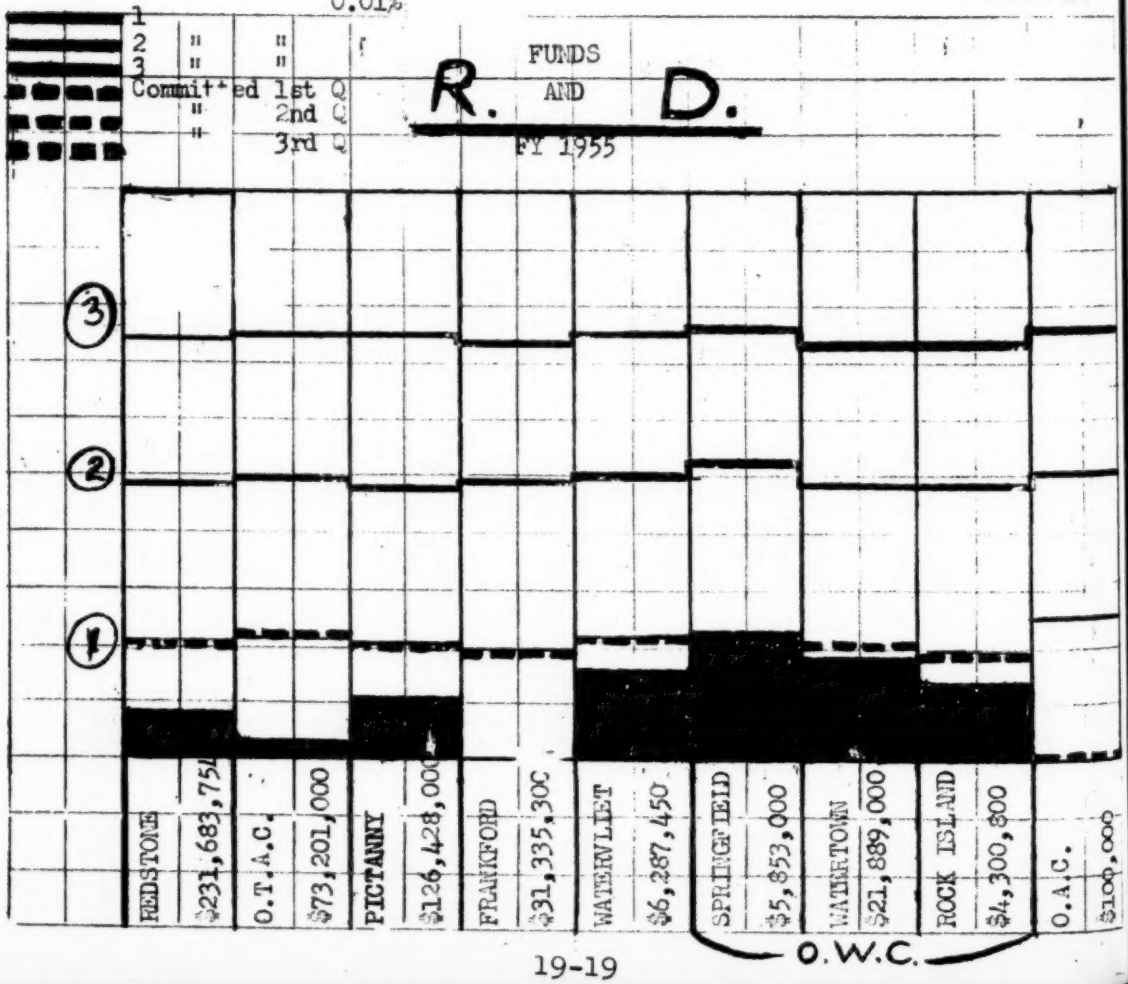

FUNDING ACTIVITY - PICATINNY ARSENAL --
PRIMARY PROG: 16
As of 1 Dec. 1954
FY 1955
TODAY
Forecast Oblig.
Actual "
Forecast Exp.
Actual "
100
90
80
70
60
50
40
30
20
10
0
1 Jul A S O N D J F M A M J 1 Jul
1954
1955
1 Allocation
2 Allot
3 Authorize
4 Obligate
5 Expend
12 11 10 9 8 7 6 5 4 3 2 1
% of Funding Program
R&D
1 Dec 5
1 2 3 4 5
ALLOCATION
ALLOTMENT
AUTHORIZATION
OBLIGATION
EXPENDITURE
SCHEDULE DATE


FUNDING ACTIVITY - O.T.A.C. - PRIMARY PROGRESS - 16
AS OF 1 DEC. TODAY
FY 1955
Key
Forecast Expenditures
Actual
Forecast Obligations
Actual
% of Funding Program
100
90
80
70
60
50
40
30
20
10
0
1 Jul A S O N D J F M A M J 1 Jul
1954
1955
DEC54
1 Allocate
2 Allot
3 Authorize
4 Obligate
5 Expenditures
12 11 10 9 8 7 6 5 4 3 2 1
Allocation
Allotment
Authorization
Obligation
Expenditure
Schedule Date

SLIDE #7

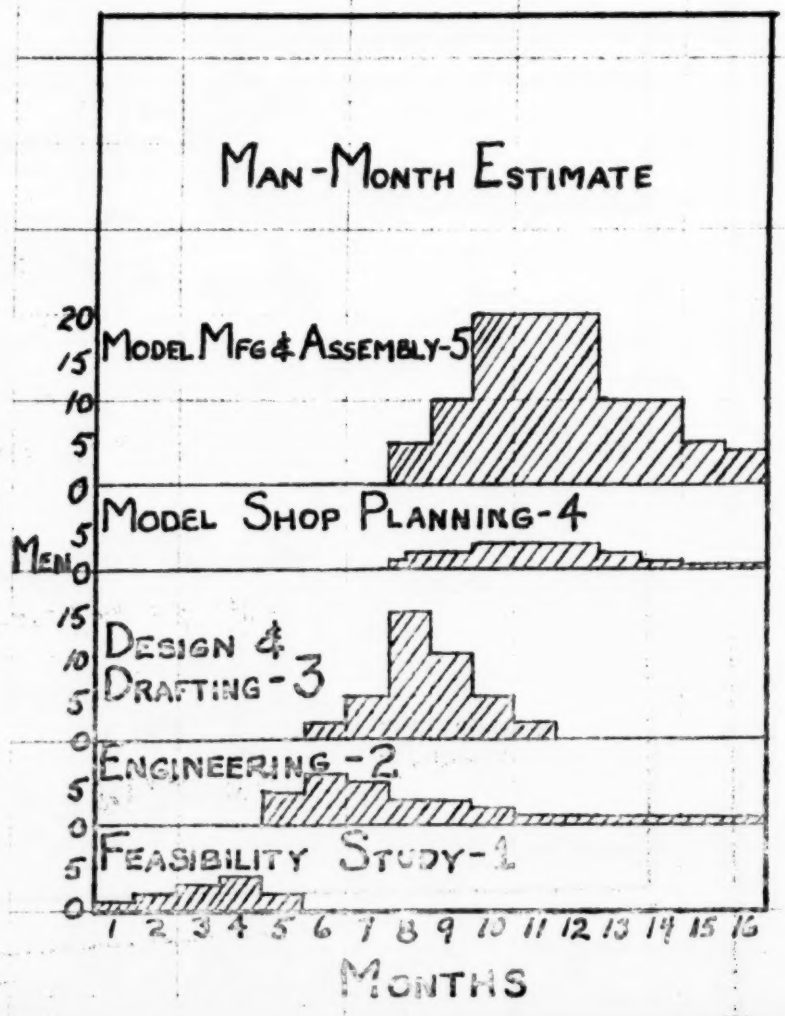
SLIDE #8


R D
FUNDS AND
FY 1955
$131,878,134.99
PICATINNY
25.24%
REDSTONE
46.25%
FRANKFORD
6.26%
WATERTOWN
4.37%
SPRGFD 1.1%
WVLIET 1.2%
R.I.A. .85%
O.T.A.C.
14.6%
Key
OAC
0.01%
SOURCE: IBM PLAN-SCHED REC
8 Dec 54


1
2 " "
3 " "
Committed 1st Q
" 2nd Q
" 3rd Q
R. AND D.
FUNDS
FY 1955
3
2
1
REDSTONE
$231,683,754
O.T.A.C.
$73,201,000
PICTANNY
$126,428,000
FRANKFORD
$31,335,300
WATERVLIET
$6,287,450
SPRINGFIELD
$5,853,000
WATERTOWN
$21,889,000
ROCK ISLAND
$4,300,300
O.A.C.
$100,000
O.W.C.

$100,000

INCL #2



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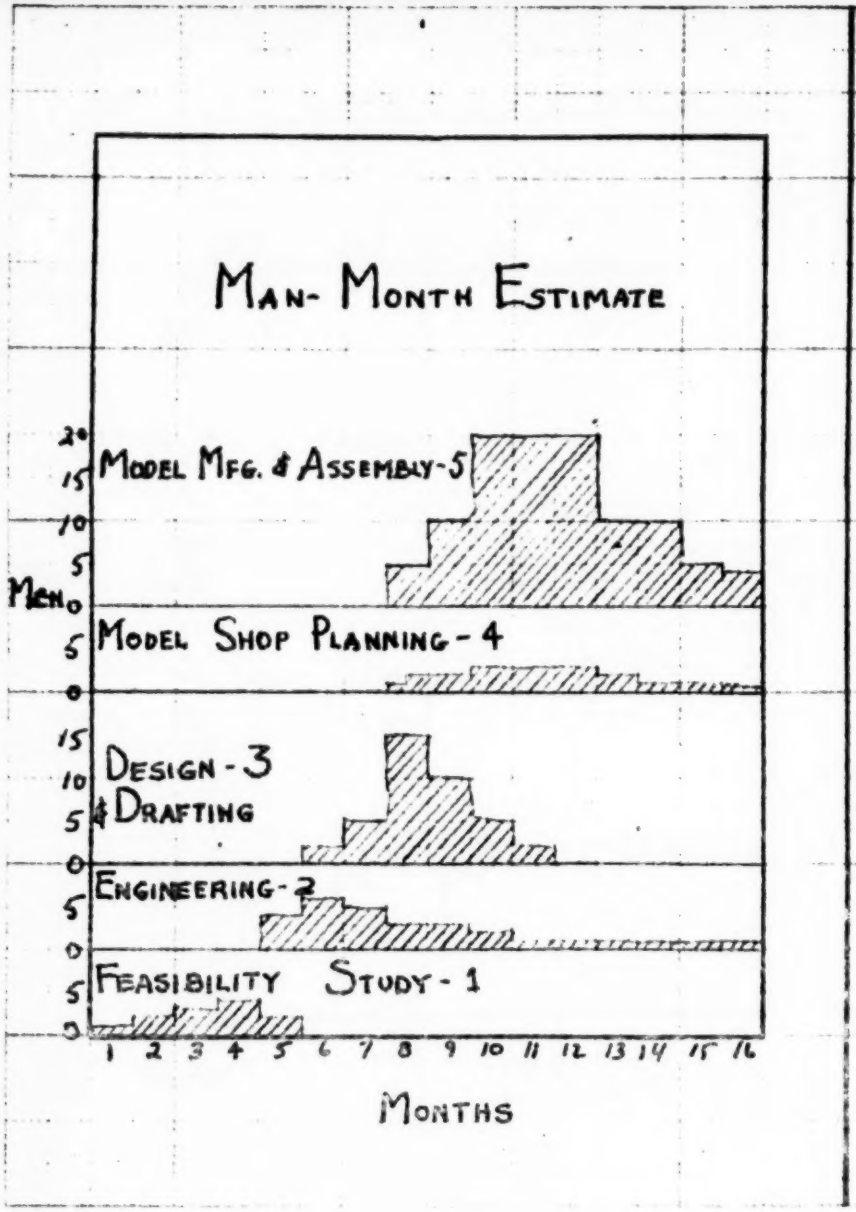
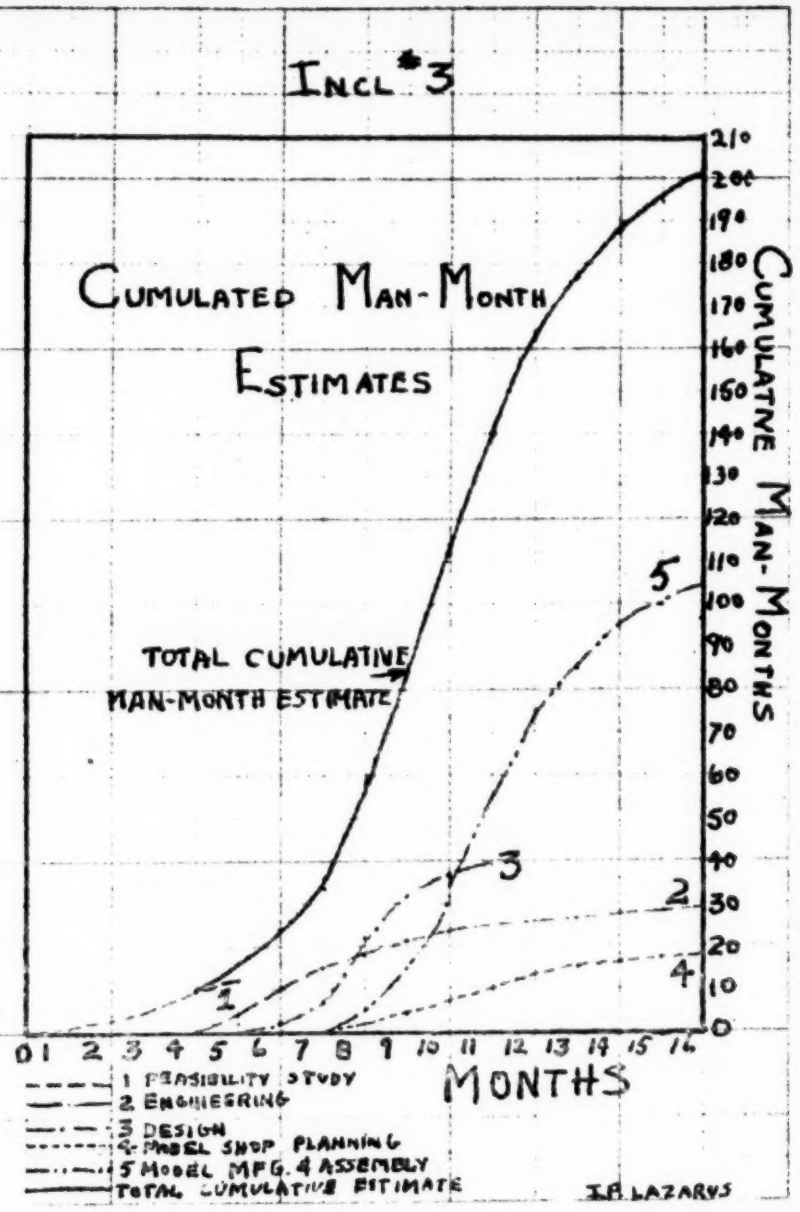
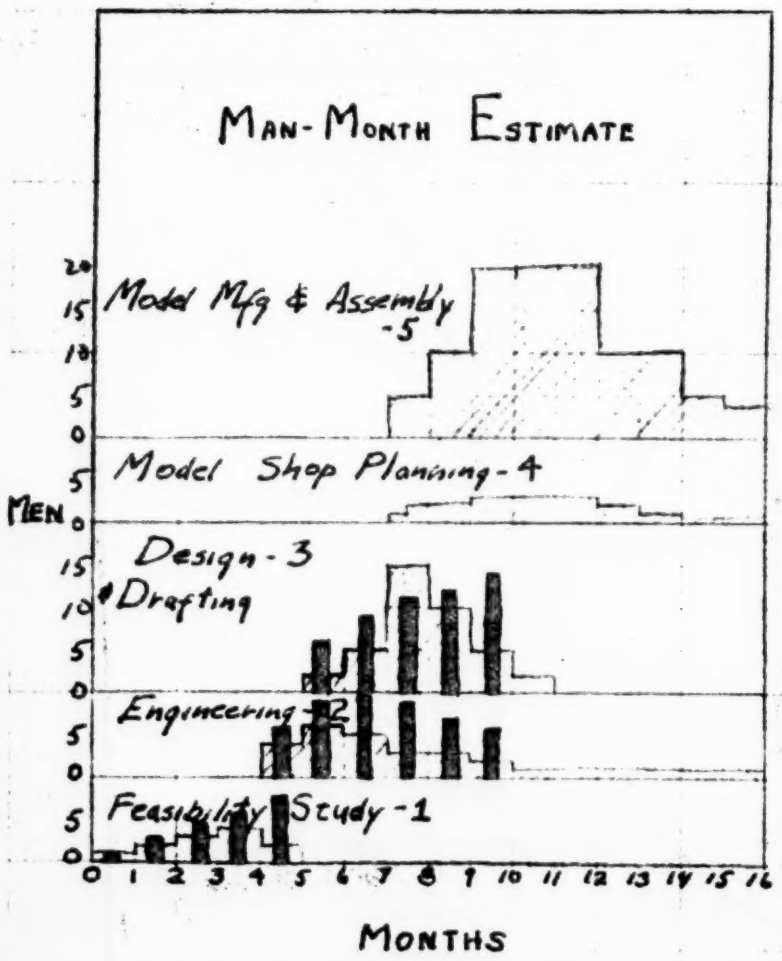
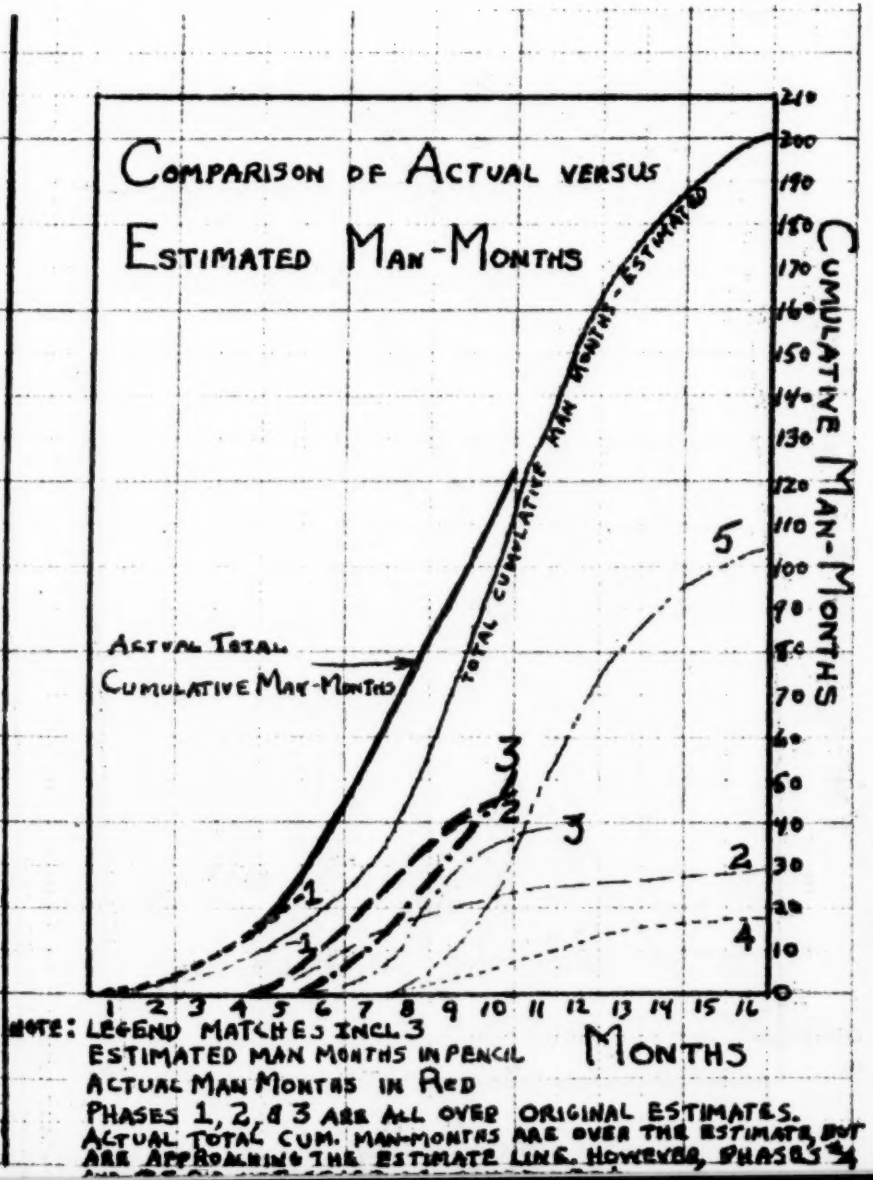

MAN-MONTH ESTIMATE
MODEL MFG. & ASSEMBLY-5
MODEL SHOP PLANNING-4
DESIGN-3 & DRAFTING
ENGINEERING-2
FEASIBILITY STUDY-1
MEN
MONTHS


CUMULATED MAN-MONTH ESTIMATES
TOTAL CUMULATIVE MAN-MONTH ESTIMATE
CUMULATIVE MAN-MONTHS
MONTHS
1 FEASIBILITY STUDY
2 ENGINEERING
3 DESIGN
4 MODEL SHOP PLANNING
5 MODEL MFG. & ASSEMBLY
TOTAL CUMULATIVE ESTIMATE
J.P. LAZARUS

INCL #4



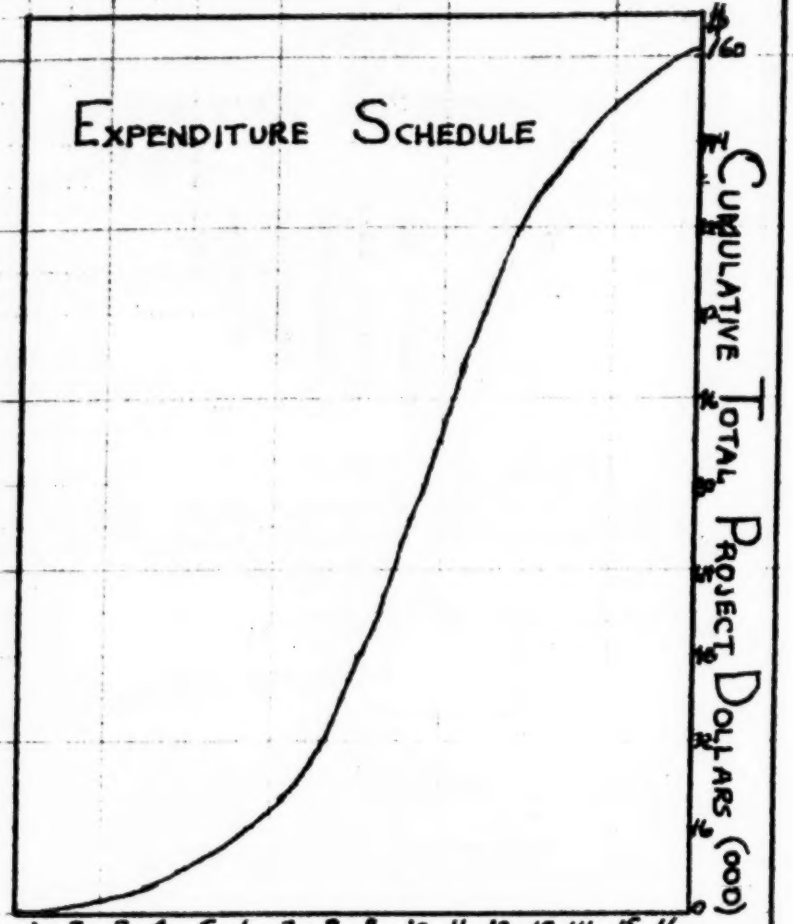


NOTE: LEGEND MATCHES INCL 3
ESTIMATED MAN MONTHS IN PENCIL
ACTUAL MAN MONTHS IN RED
PHASES 1, 2, & 3 ARE ALL OVER ORIGINAL ESTIMATES.
ACTUAL TOTAL CUM. MAN-MONTHS ARE OVER THE ESTIMATE, BUT ARE APPROACHING THE ESTIMATE LINE. HOWEVER, PHASES #4

I. LAZARUS

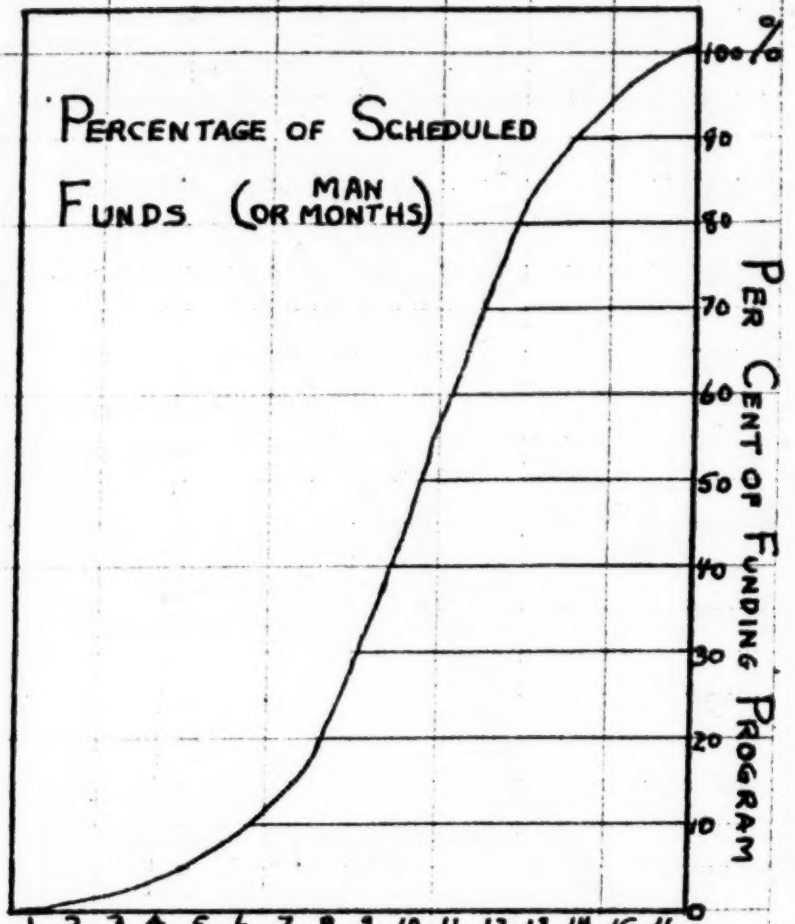
SLIDE #11

INCL #5a.



NOTE:
Avg. Monthly Salary (GS-9) = $453.
Plus 75% Overhead Added = 340.
Total Monthly Charge per Man = $793.
Times 200 Man Months = $158,600.

INCL #5b.



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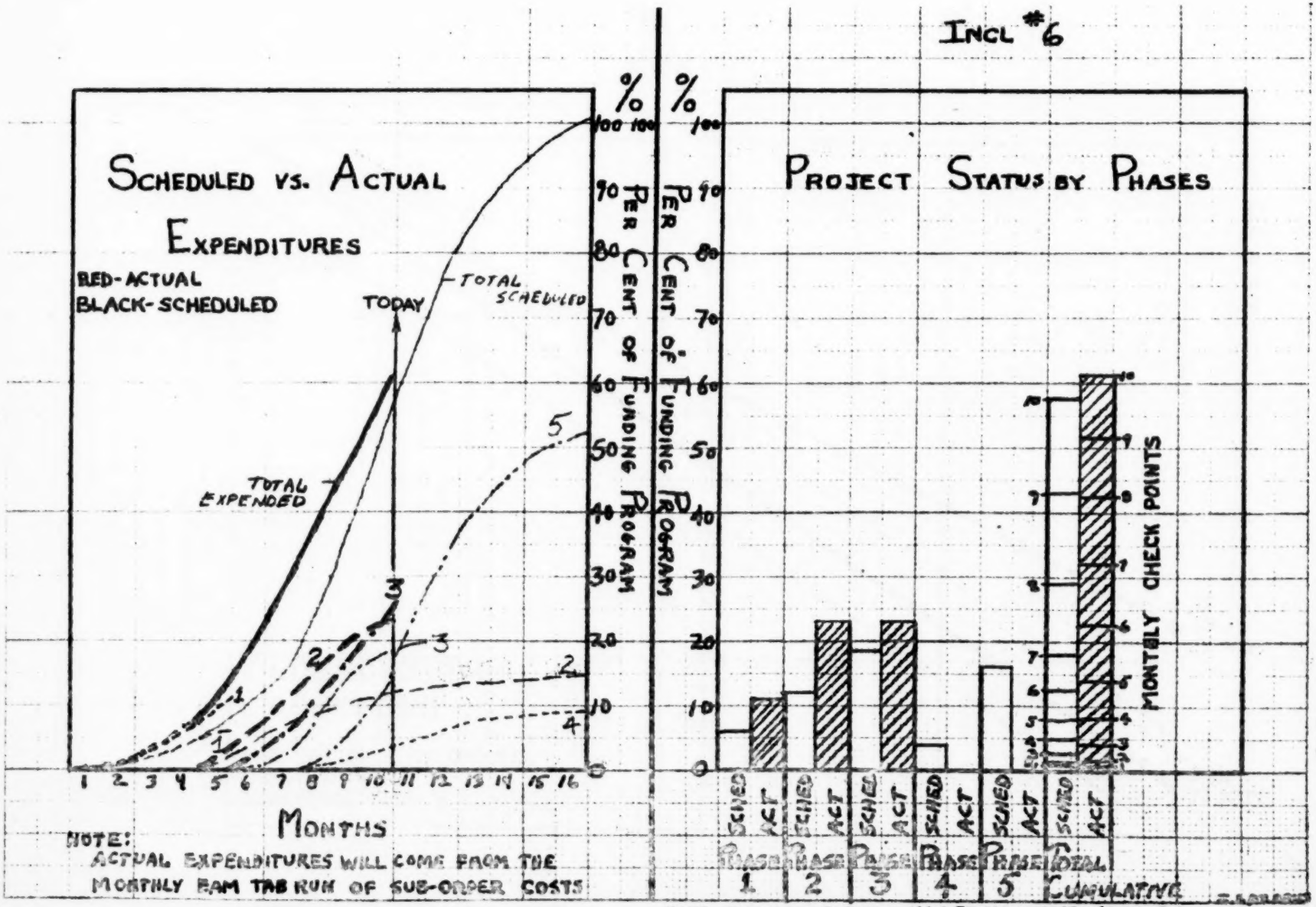

NOTE: THE ABOVE CHART MAY BE MAINTAINED ALSO ON MAN-MONTH PROGRESS STATUS IF DESIRED

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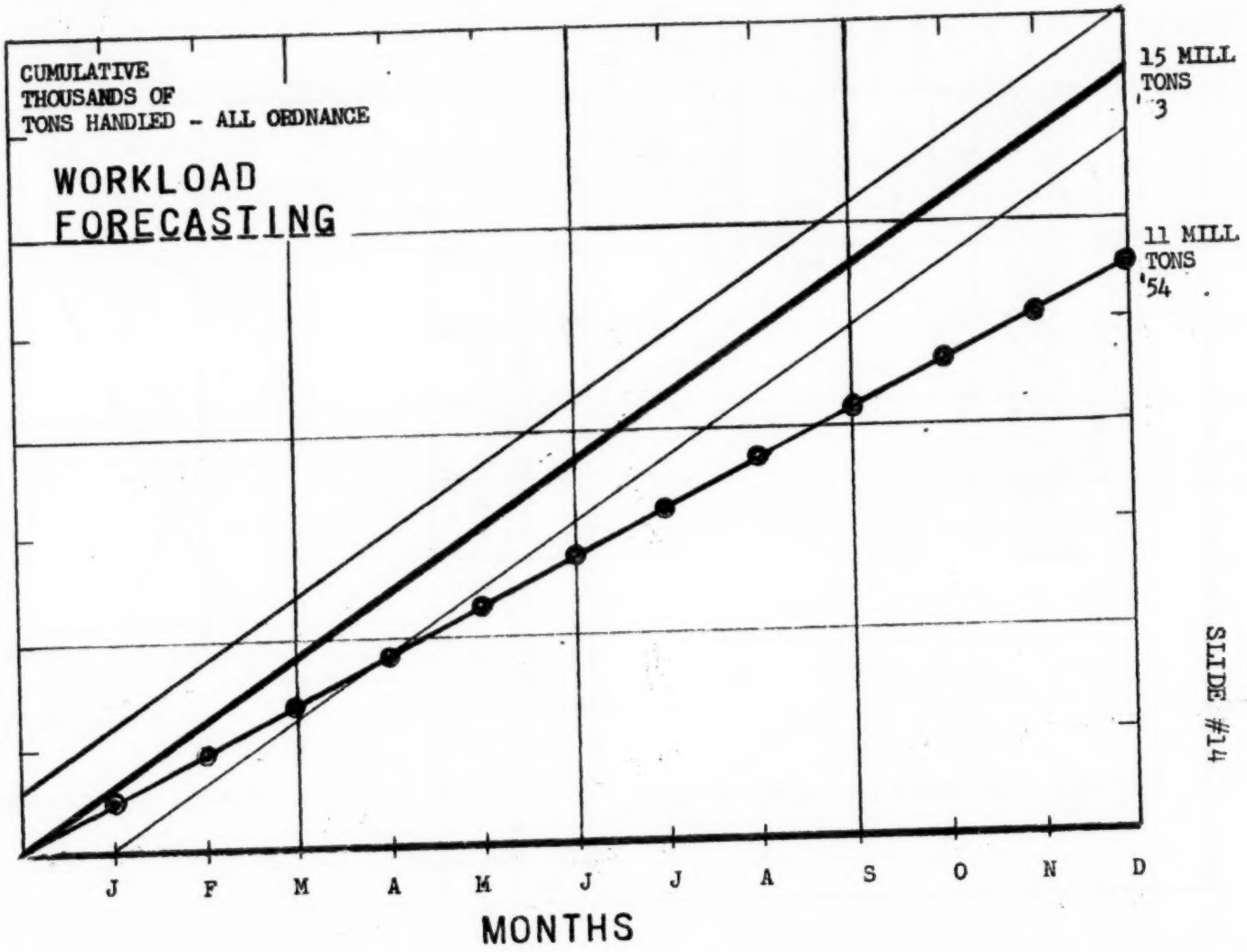

SLIDE #14

* SOURCE - ORD. STATISTICAL DATA HANDBOOK

ORGANIZING FOR DATA PROCESSING

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Anderson-Nichols & Company
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Introduction

The tremendous interest in the new methods of data processing made possible by electronic devices is shown by the rapid growth of descriptive literature and by the increased attention given to the subject in meetings like this one. The influence of the ideas presented here, the thought and study and change which will result, can govern the direction, magnitude and rapidity of this modern industrial evolution. While the changes to come in the lives of industrialists, white-collar workers, and laborers cannot be clearly foreseen, the good and evil results will tend ultimately toward the betterment of all modern living if we temper our changes and our progress with human understanding and compassion.

The problem

Our particular concern is the organization of a business for data processing. This discussion will include the birth of the idea, its growth during a study period and its maturing as a definite program. Effects on company policy, preliminary costs, organization changes and educational programs cannot be discussed in detail. It is the philosophy of approach to a detailed study with which we will be concerned in this paper.

The birth of an idea

Before any real progress can be made, someone fairly high in the organization of a company must accept the possibility that this new subject of electronic data processing may have significance for the future of his company. Perhaps the comptroller, or a vice-president, or even the president, is intrigued by a magazine article, an advertisement, or a comment from a fellow executive. No matter what the stimulus, if he responds and starts to examine the subject he will very quickly uncover a great mound of literature. The ideas presented are likely to be so diverse, so general, or so detailed that he soon feels the need for support. The breadth and complexity of the subject is overwhelming, but the probable value to management can still be recognized.

The idea grows

The logical next move is to form a small executive committee to investigate the various phases of the subject. This work will require the time of well paid executives and will be in addition to their normal work load, so the formation of the committee must usually be acceptable to the president or executive vice-president. The membership of the committee will depend on the organization of the company but should have representation from the major operational groups, such as finance, purchasing, production, engineering, warehousing, and sales. The reason for such diversity is that the

implications and effects of electronic data processing are certain to be felt throughout the whole structure of a company. Divisional and departmental lines cannot be maintained as a rigid barrier to the flow of detailed information in a well planned automatic system. Therefore the more understanding and support generated at the top levels of management the smoother will be the eventual transition to a working integrated system.

The objective of this committee will be to reach a decision - the company should or should not initiate a formal program of study in expectation of installing an integrated electronic data processing system. To reach this decision the members of the committee must acquire a general understanding of the nature of integrated data processing systems made possible by new types of equipment. They must recognize that in general all data when first generated should be recorded in a machine-recognizable form. They must understand that these data can be automatically stored, transferred and manipulated mathematically under the control of complicated programs in a machine system. They must not refuse to accept the idea of allowing records of business transactions to be accumulated, maintained up-to-date, and reported to management by machine, according to systems and procedures carefully worked out long before the equipment is installed.

For example, they should consider the problem of data handling in an order-billing procedure for a warehouse operation. Installation is now underway on a system in which orders as received are entered on an electric typewriter by stock number and quantity. The typewriter is electrically connected to a computer in whose store is the inventory record for all fast moving or critical and expensive items. The stock number locates the information in storage, a comparison of the inventory level with the quantity requested is made by the machine and if the order can be filled the computer sends to the typewriter the unit price of the item and the extension by quantity. The inventory level for that item is adjusted automatically. Then the next item is entered by the typist for similar action. If the stock is depleted the computer will not complete the line, or will indicate a partial order and a back order. At the same time it will type out at a supervisor's desk the information about the back order so that purchase action can be initiated. This should be an unusual situation because a reorder level in the information store should cause purchase action before the stock becomes significantly depleted. This reorder level can be changed periodically in the light of order activity, leadtime and other factors evaluated by human judgment.

As the typist fills in the order the resulting information is automatically typed in the warehouse as an assembly sheet and shipping document. Picking tags can be generated at proper strategic points in a large warehouse system for maximum efficiency in assembling merchandise. And typewriters at the receiving dock can be used to record directly into the inventory record the receipt of acceptable merchandise for storage in the warehouse.

Information such as item activity, dollar volume by item or class or customer, new unit prices, customer credit, accounts receivable, due-ins and due-outs can all be tied together in the computer system. Those topics which require rapid action and up-to-the-minute information can be handled on a random access basis, while other information can be stored on transaction tapes and accumulated for reports or historical records at a later time.

Even in this simplified situation it is at once apparent that the system is based on information flow patterns rather than on administrative divisions. An awareness of this possibility is of major importance to the activity of the executive committee.

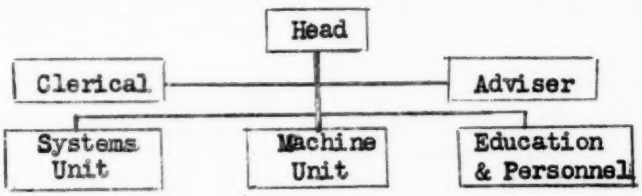
It is apparent that the executive committee can arrive at a decision without a detailed study of the systems and procedures of the company. Instead, they should consider such questions as "Does the information stored and handled in some departments overlap that in others? Is the information available in some departments not transferred to others where it would be useful, because of lack of time or facilities? Is most of the information available to management of historical value only, because of excessive elapsed time? When sudden changes in business conditions occur is it impossible to gather or process pertinent information fast enough to aid in reaching significant decisions? Are inventory levels higher than economically desirable because of lack of timely control? Is production control failing because of lack of timely information from sales? In short, is the generation and flow of information insufficient and too slow for the best management of the firm?"

A really open mind is needed to get fair answers to such questions. How often we meet the man who has built his department into an empire, and is afraid to consider any changes whatever! Sometimes we find the attitude, "The business is making money so why change?" But an increasing number of executives are aware of the possible advantages their competitors may gain from better data handling procedures and are willing to look inquiringly at their own methods.

Maturing a definite program

If the answer to many of the preceding questions is affirmative, the committee will decide that a more thorough study is needed.

The general procedure at this stage is to form a Working Group. The group leader, perhaps from the committee, should be enthusiastic but realistic about the whole affair. He should work at this as a full-time assignment, with clerical help, a competent technical adviser, and a small staff. One or two men for systems and procedures analysis, another two for machine systems and operations, and a specialist in education and personnel matters would make a good supporting staff. These staff people should be drawn from the roster of company employees, for their knowledge of the company will be invaluable. The adviser should have had experience in developing electronic data processing systems, and he may well be on a contract basis from a consulting firm outside the company.



The members of the Working Group must become thoroughly imbued with the spirit and philosophy of modern data handling concepts. This will require training, for although most business offices already have many people who handle information, their experience is generally limited. Use should be made of the executive courses offered by the various computer manufacturers, and of the special two or four week summer courses offered at a number of colleges and universities. These will provide a broad background for understanding the general characteristics of modern information systems, and the problems of re-examining the data systems of a company. The staff should train together, as a group, and should be aware of one another's attitudes and concepts. The members of this staff will become the management of the final data processing activity in the company.

But in addition to this general training, at least some serious exposure to programming a computer should be included in the education of the Working Group. For it is virtually impossible to understand the requirements for extremely careful and detailed analysis of data systems until one has actually been through the throes of programming, coding, debugging and running even a moderately simple problem. It does not matter too much for which machine the problem is prepared as long as an opportunity is available to carry it through to a successful conclusion.

After this indoctrination the Systems Unit will turn their attention to the problems of collection and use of data within the company and the Machine Unit will begin to acquire a detailed understanding of the various commercially available equipments which might be used by their company. After these steps have reached a point of diminishing returns, the two Units should begin working together to determine the most satisfactory method of handling the company's data processing requirements. Detailed cost and equipment studies will be required because a decision in favor of a specific make of equipment should be prepared at an early date.

The members of the Working Group have an important management function. They must be able to get along with people, both within their own group but especially with others throughout the whole company. They will be the spearheads of change, and will be resented by others unless they are skillful and tactful in their approach to new areas. They must inspire confidence and cooperation during the growth of the new system, and they must be competent managers when the system is in operation.

Planning and controlling the operation of an automatic information system is similar to supervising a group of people, except that it is a more exact process because details and exceptions cannot be left to human judgment. They must be foreseen. A sense of logical sequences and system relationships is almost a necessity. A mechanical sense or scientific aptitude may be of great help, but the primary need is to be a good manager of people.

A working plan

The objective of the Working Group is to devise and establish a modern data processing system in the company. This should be done according to a carefully worked out plan, with objectives and target dates clearly defined.

Otherwise the probability of bogging down in details is almost overwhelming. In organizing such a plan, consideration must be given to the objectives and requirements of the final system, and to the limits imposed on these by the nature of the company.

One method of using electronic computers is merely to replace existing manual or machine methods, with the hope of increasing the speed of processing data. This does not make use of the potential of properly selected electronic equipment and suitably developed procedures. Instead, it is advisable to prepare flow charts of the major operations of the company. These should define the sources of information and the sinks, or places where the information is required for analysis, control and historical records. Association of company activities on the basis of their information requirements should result from this study, and then one of these sets of associations should be analyzed in detail. This will include the following tasks.

1. Study and classify the work to be accomplished (not the operations now used) in receiving, processing, and dispensing information.

2. Determine the volumes of data handled under average conditions, peak work loads, and probable future conditions.

3. Evaluate the relative importance of various classifications of work, and the realism of volume information as determined.

4. List and evaluate the relative importance of all factors which are intangible or for which definite measurements are impossible or unreliable.

5. Develop alternative methods of accomplishing the work, including manual and machine methods as well as electronic applications.

6. Evaluate the relative worth of the alternative solutions, within the practical operating conditions of the company, and with respect to its over-all data requirements.

7. Prepare a summary report for decision to implement an area of work, or to postpone it until broader studies have been completed.

8. Coordinate all proposals and decisions with all organizational elements affected.

9. If implementation is approved, develop specific plans for new procedures and for the change-over period. Careful thought and skilled judgment are required.

10. Select and train personnel in new procedures and in making the change-over.

11. De-bug procedures as much as possible, install equipment and develop smooth operation.

12. Prepare a final report on the new system and recommend steps for further development.

The working group will need help from the various activities included in this program. One of the best ways to ensure cooperation in new plans is to make each affected group a participant in terms of its own requirements. This does not always work smoothly but it is worth trying. It may also uncover people in the company who have interests and capabilities of value to the working group, for its future growth.

Everyone concerned with the activities of the working group must recognize that this work is slow and costly. Many man-years of study and analysis have been spent by the pioneers in the use of these new concepts and equipment. Several hundred thousand dollars may be needed for all the preliminary costs before a large system is installed and operating satisfactorily. But there is increasing evidence that carefully thought out systems will pay off, especially in such intangibles as increased efficiency, better management, reduced waste and increased customer satisfaction. Automatic data processing systems are primarily management tools and their use should be directed toward the smooth operation and healthy growth of a company.

Personnel relations

So much publicity has been devoted to the number of people who will be put out of work by electronic computers that it is inadvisable to publicize the initial activities of the Executive Committee. The effects on company personnel, policies, and organization must be examined. These subjects will require careful, sensitive investigation for they can be explosive. A poorly conceived or tactless approach can set back the new program for an indefinite period. Once the decision to form the Working Group has been made, the personnel man should begin to prepare the company employees for whatever changes may occur. Some simple educational literature on the nature of automatic data processing systems should be distributed. Emphasis should be on the elimination of drudgery, the growth of new jobs with greater responsibility, and the use of normal attrition to take care of any personnel reduction. It can be said that the company hopes to handle increased business without a major staff increase with the help of automatic systems. Human beings will still be needed, especially in activities where judgment is a major factor.

Educational programs on the general principles and use of automatic devices are advisable for all staff and supervisory personnel. These equipments are not nearly so mysterious as they first seem, and relatively few people will be concerned with the details of their operation and use. It is important that their function and capabilities be understood. A good instructor can be a major aid in the development of satisfactory understanding among management personnel. An automatic data processing system should not be static but should become more and more useful as new ideas are developed by those who depend on it.

The effects of size

The most vocal groups planning to get automatic data processing have been the large companies or the government services. Their problems are admittedly serious and demanding. But the very size of the problem, the volume and complexity of the data, make a realistic solution that much more difficult. It seems probable that the medium sized company, adapting its more easily understood problems to a moderate sized computer has a better chance of really putting into practice the benefits of an integrated data processing system, according to our modern concept. This area deserves more attention from all who are interested in the future.

INDUSTRIAL ENGINEERING IN TRANSITION

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Director of Operations Research
Booz, Allen & Hamilton
Chicago, Illinois

Only ten short years ago our country was struggling to re-establish a peacetime economy, which we fervently hoped would be a better, more abundant one. We knew of the engineering and scientific wonders that had been created and implemented in theinterests of survival and for the protection of the free world and we had faith that some of these developments would be useful to man in the new era in front of us.

However, only a few foresaw that we were to enter such a fantastic period of economic growth and technological change that we would begin to hear of these times referred to as the 2nd Industrial Revolution. Whether the events of the past and present decades are significant enough to warrant such a description only time will tell. However, it could and should be noted parenthetically that <u>even</u> revolutions happen <u>faster</u> in this modern world of high speed communication, self enlightenment and measurement -- all catalyzed by our competitive economy.

Bubbling all around us are the results and symbols of this unparalleled period of change and abundance. We hear daily of Atomic Power, the Mighty Force of Research, Electronic Computers. We have digested television in stride - although it takes a little bicarb from time to time. Automation, feedback control and Operations Research are representative approaches in this new world and we have become quite accustomed to establishing building construction and manufacturing production records with ease. And we have learned to use governmental power to establish what it is hoped is a stable and self-controlled economy. And during this period management, itself, has learned to plan, to innovate, and to borrow and utilize the concepts of military strategy in guiding the corporate course. Truly, the combined effect of all of these factors has been to create a more dynamic, a more change-oriented economy and a higher standard of living for all segments of the population. <u>It would seem that all of this indeed is what Revolutions are made of!</u>

What has all of this to do with Industrial Engineering? Industrial Engineering has long performed an important part in aiding management in the analysis, design, and control of the operating phases of the organization. Also, the ranks of present day management are being composed increasingly of men who have been academically

trained in the principles of scientific management, engineering analysis, and the methods, viewpoints and values of Research.

This has resulted in an increasing reliance upon engineering and scientific approaches in the process of decision making. The industrial engineer has aided management immensely and has been called upon in this regard to the extent that the number of practicing industrial engineers has grown over 350% in the 10 years ending in 1950. In the process, industrial engineering has acquired new methods, has become an organizational entity in industry, and is establishing a mathematical-engineering basis for the profession in both the academic and industrial areas. It is in this light that we may look at Industrial Engineering in Transition.

In my opinion there are 5 major aspects of this "Revolution" that are important in causing this transition in industrial engineering. I shall list them first and then discuss each briefly:

1. A greater Consideration of Human Values and Motivations in the Operations of the Enterprise.

2. The development and implementation of strategic concepts in business management.

3. The Increasing Rate of Technological Change.

4. The advent of Electronic Computers.

and 5. Our growing ability to use mathematics and models in the analysis and engineering of management systems.

These are all somewhat independent effects as you will observe which when synthesized produce the economy of abundance we now experience. The industrial engineer is in an enviable position, for he may serve as the catalyst for this synthesis and help guide the course of these activities and make this revolution a practical reality.

Let us take a brief look at each of these factors mentioned.

1. <u>A GREATER CONSIDERATION OF HUMAN VALUES AND MOTIVATION IN THE OPERATION OF THE ENTERPRISE</u>

Here, we have seen that the objectives of many enterprises are gradually being spelled out formally in terms of both the human and economic values. These policy guides permit more straightforward industrial engineering. Development of such formal

statements of company objectives are partly a resultant of mature collective bargaining, partly a pragmatic decision on the part of management and partly a function of the unusual prosperity that has become characteristic of the past decade. In any event, management is turning to the industrial engineer for more comprehensive and accurate treatment of the problems involved. As a result, we are noting significant changes in the scope and design of wage incentive systems, work measurement and evaluation systems. These systems are now being designed with much more regard to their total effect on Labor Management relations, and, arguments over accuracy in time study practices are no longer as fiercely debated. Thus I.E. practices are turning more in the direction of aiding the overall objectives of the enterprise.

2. THE DEVELOPMENT AND IMPLEMENTATION OF STRATEGIC CONCEPTS IN BUSINESS MANAGEMENT

Modern management has borrowed successfully from the military, both by observation of the methods used and also by direct counsel and employment of military strategists. Such men as Gen'ls Somervell, MacArthur, Smith and many others, are excellent examples. This, coupled with better forecasting means, has given management a greater mobility in moving in on opportunities and in eliminating unprofitable ventures. The resultant has been to free management's natural ability and desire to innovate, to experiment, and to take calculated risk. This philosophy has permeated throughout many organizations, giving younger management the opportunity to catch the full importance of management of an enterprise. Thus, the problems of establishing control are not now as important as the analysis of the opportunities available, obtaining efficiency of the installation of a new plan and the decreasing of the time in the learning process.

3. THE INCREASING RATE OF TECHNOLOGICAL CHANGE

Augmenting the above are the by-products of our tremendous investments in research over the past 15 years. New materials, new products, new gadgets are being developed at what appears to be at an ever-increasing rate. This explosive technological growth is exemplified by the growth of the electronic industry. All this indicates the need for faster - more efficient introduction of change; and the need for greater flexibility in our control systems. The industrial engineer is learning to deal with these problems by use of Time Reduction Curves, by cooperation with market research and by anticipating the output of physical research. The emphasis is now more adequately including the macroscopic - i.e. analysis of the system - rather than the microscopic type of approach which was geared to control of the individual worker.

4. THE ADVENT OF ELECTRONIC COMPUTERS

This may be the most significant item in the list as soon as we learn how to use them adequately. Industrial Engineers are beginning to see and test the feasibility of certain mathematical techniques, to revitalize concepts of control and to do a more effective job of integrating various reporting systems. This has caused Systems and Procedures work to receive increasing attention and has brought the industrial engineer directly into the picture of evaluating computers for management. We haven't found completely suitable ways in which to evaluate the economics of utilizing computers. Decisions made to install a computer are therefore often not based on tangible direct dollar returns. Perhaps this is fortunate. I believe it is. For management intuition has thus taken over and made the decision to use computers. In a sense the computer has become a strategic weapon, an instrument of potential competitive advantage and we have a break through that is forcing us to learn and to utilize the great potentialities of these machines. Perhaps the greatest returns from this will come from. . .

5. OUR GROWING ABILITY TO USE MATHEMATICAL MODELS IN THE ANALYSIS AND ENGINEERING OF MANAGEMENT SYSTEMS

Perhaps this point is best illustrated by the excellent program you have come to attend. You will hear of many new approaches and practical applications of mathematical and simulation techniques to systems design, programming and control problems. The collective papers presented at this meeting will give you an excellent operational definition of the nature and extent of the transition of industrial engineering. It is in this last area that we can expect the continuing stimulus of new viewpoints and approaches to increase our proficiency in analyzing and designing management systems.

Management has long ago learned how to organize for physical research and to develop the long range latent returns possible. This required great faith on the part of the original companies engaged in the research approach. This approach is now generally accepted.

Management is now showing a faith in the approach that research into business systems and operations will likewise produce long range, effective and handsome returns on the investment. Thus we are beginning to see the development of research organizations, quite often within the industrial engineering function, which delve into the structure and basic make-up of the business, staffed with a goodly number of individuals who have a point of view more nearly akin to that of the classical scientist who is motivated more by his own desire for understanding than by the direct material gains from his efforts.

Reflecting back on the development of "engineering" itself for a moment, we note that it has been characteristic of the engineering profession in America to develop along the lines of problems currently needing solution in our economy and society. Prior and during the war years other engineering disciplines were engaged in a fundamental shift from emphasis on the "practical" and experimental approaches - the art of engineering - to the use of mathematical methods of analysis refined through cooperative work with applied scientists, mathematicians and other engineering disciplines - i.e. "the science of engineering". Thus the present day engineering profession is characterized by the development and use of a considerable "research" function which develops new analytical approaches and probes into the basic structure of our physical world.

Thus my point is squarely this - that this same sort of approach is pervading the industrial engineering profession, offering the opportunity to develop in an accelerated manner along similar analytic and research lines. This is the subtle transition in which the industrial engineer is engaged. The evidence that this is true is real and compelling.

1. Management is back of it. We have discussed this in several aspects, namely, managements' faith in research and its desire for growth and change. One other point that should be mentioned is that many companies now conceive of industrial engineering as a staff function serving more often as a flexible, consulting, problem solving group capable of analyzing <u>all</u> problems in relation to operations rather than as a time study, cost control department.

2. Engineering colleges are revising curricula to include more adequately the mathematical approach in management systems, and in most cases are looking to the industrial engineering department for leadership. Courses in operations research, systems analysis, mathematical programming, management sciences, computers, etc. are becoming widespread.

3. The AIIE has developed to fill the void between industry and the academic. It has developed a fine <u>Journal</u> which reports fundamental work in these areas and also performs a translating function of work done which is sometimes not understandable due to the research language used in reporting it. AIIE has also developed a <u>definition</u> of Industrial Engineering which is serving as a guide for the further development of the profession. And the Institute is being accepted in the overall engineering family as is evidenced by its recent institutional membership in E.J.C. and A.A.A.S.

4. Within the past 5 years we have been aided immensely by the development of fine publications and meetings by the Operations Research Society of America and the Institute of Management Sciences. We thus have a research arm - in fact two of them - which are providing the industrial engineer with theoretical as well as applied models for his consideration. Truly the industrial engineer has more to work with than ever before in his history and quest for a scientific basis in management. However, this is not all a bed of roses - various disciplines such as economics, physics, applied mathematics and statistics as well as other branches of engineering are all vieing to serve management. The professional lines once more clearly delineated are now being overlapped. As a result there are a plethora of techniques available, couched in different jargon and often in actuality merely alternate methods for solving the same general problem. This often poses a serious dilemma to the industrial engineer in selecting methods to employ in structuring and solving his problem.

Thus, in summary, industrial engineering is making the same transition other branches of engineering have made and we can look forward to aiding in the research, as well as serving as the translators, and to being the designers of organizations, the work situation and various types of controlling systems involving men, materials, machines, methods and information. Perhaps a distinguishing characteristic of the industrial engineer in this brave new world of change will be his ability to successfully install his design and his willingness to be responsible for its successful performance.

In any event, Industrial Engineering has experienced a phenomenal growth during the past five years and the future seems to hold even greater promise. I am certain that the next two days and the excellent program which the Washington Chapter of AIIE has so painstakingly prepared for you will give you a better and more realistic impression of the scope and aims of industrial engineering than these words of mine will have conveyed. Listen well and borrow freely from the essence of this transition.

INDIRECT WORK STANDARDS

Harold B. Maynard, President
Methods Engineering Council
Pittsburgh 21, Pennsylvania

I do not mean to imply that it is unnecessary to study and measure repetitive work in order to improve methods and to establish realistic standards. Of course it is and because it pays we do it all the time. But if it is possible to reduce costs and increase profits by studying and measuring the work which is easiest to control partially at least without measurement, how much greater is the potential which exists in the measurement of indirect labor. It is more difficult to measure indirect labor and establish accurate standards than in the case of direct labor, but it can be done in ways which we shall discuss presently. The savings as I have said are often greater than those that result from direct labor measurement.

The fourth cause I gave for the growth of indirect labor is the trend towards better mechanical equipment and ultimately automation. Equipment is becoming increasingly complex and usually requires greater maintenance. On automated lines where the failure of a single minor part may cause the shut-down of a whole process, an intensive preventive maintenance program becomes a must. These factors mean that over-all indirect labor costs particularly in the tool and maintenance areas will continue to rise. Thus it is evident that it will be increasingly necessary for management to change from its traditional acceptance of indirect labor as a necessary evil about which little can be done to an aggressive attack on the problem which will reduce indirect labor costs and bring them under strict control.

Experience has shown that standards can be established for almost any kind of indirect labor activity. Actually, however, this is only a small part of an effective indirect labor cost reduction program. There is a great deal that must be done before conditions are such that standards that mean anything can be established. Unless a company is willing to undertake the whole program, it is likely to be disappointed in the results it gets.

Management is always looking for simple solutions to its problems and properly so. It is possible to go so far in the direction of simplification, however, that the results are valueless. A jack knife, for example, is a good deal simpler than a precision lathe. If, however, a cylinder must be produced which is perfectly round and accurate to the thousandth part of an inch, the jack knife would be entirely unsuitable.

Many attempts have been made to develop standards for indirect labor which are just as impractical as this example. A favorite that has been tried many times with little if any satisfaction or success is to relate the assumed performance of indirect workers to the measured performance of the direct workers they serve. Such a plan is easy to set up. It can be done in the accounting office on the basis of past statistics or even around the bargaining table on the basis of the outcome of claims and counter claims. It does not take any very deep analysis to see that plans established in this manner are of little value, for they do not take into account much of anything but what has been done in the past and/or what it is hoped somehow will be done in the future. A plan of this sort does not involve managing in any sense of the word. It represents the failure of management to perform the function of managing in the hope that a mechanistic plan will somehow do it for them.

Lest this seem like too harsh an indictment, let us see what must be done to establish what the methods engineer would consider to be an adequately designed program for the reduction of indirect labor costs.

Many years ago, Taylor developed a formula for obtaining high production. He said, "The greatest production results when each workman is given a definite task to be performed in a definite time and in a definite manner." We have all applied that formula again and again to direct labor operations. It is just as applicable to indirect labor activities.

Let's consider the definite task first. Tasks for indirect labor are sometimes established quite superficially. There are two different types of task assignment for any given kind of indirect labor activity. These are

1. Specific job assignments.

2. Specific area assignments.

The former are usually the more effective. A maintenance man is directed to "Repair Machine #25 in Department A," or a laborer is asked to "Unload a truck load of lumber and stack it in Department B." If a good scheduling and dispatching setup is used, the scheduling of specific jobs will help to reduce lost time.

On the other hand, it is much easier to give task assignments by areas. A foreman will say, "I need another material handler to take care of the increased workload in my department." If management accepts this, the material handler is added. No one

has to worry about it much thereafter. The material handler will manage to look busy when he is in sight, and it's easy enough to disappear in most shops when there is nothing much to do.

The proper assignment of tasks requires a good deal more study than this. Some years ago, the foreman of a shipping department was falling behind. He requested more men and management agreed. When this did not help, he asked for and got still more people. This went on until he ran out of room. He had built up his staff to 45 people and was further behind than ever. Finally he called on the methods engineering department for help. After a careful study of the work, the force was reduced to 16 people who were assigned specific tasks to perform. Only then did the work begin to flow. Adding more people to bolster up a lagging activity is seldom the correct answer if the work has not first been properly organized.

The highest cost man in a department may well be the laborer rather than the most skilled mechanic. The mechanic may get $2.50 per hour and the laborer only $1.50, but if the laborer is only busy half the time, his true cost is $3.00 per hour. In many cases, the principle of the division of labor can be carried too far. It may be less costly to have a mechanic do his own material handling, than to have it done by a lower rated laborer who is busy only part of the time. Indeed, the best form of task assignment is by no means obvious in such situations as a large department involving many mechanics and several material handlers. With such factors as varying labor rates, cost of idle machine time, and cost of idle man time involved, the most efficient setup can perhaps only be worked out by mathematical analysis, involving some of the newer operations research techniques.

We will find it useful to classify tasks in two ways.

1. Specific.

2. Indeterminate.

One of the steps of effective organization of work is to change the indeterminate tasks to specific tasks. A new janitor is hired for Department C. He is shown a closet containing the usual janitors' supplies and is told that it is his job to keep the department clean. In this case, his task is indeterminate. What he does and how he does it is left pretty much up to him. When his task is made specific which is certainly easy enough to do if management decides that it is ready to manage, departmental cleanliness will improve or cleaning costs will go down or both.

So much for the task. I hope that without laboring the point unduly I have been able to say enough about the importance of organizing the work properly before going further to emphasize the necessity for doing so.

Taylor said that in addition to giving the workman a definite task to do it should be done in a definite manner. Today we refer to the manner as the method, but it is just as important for management to pin down the method today as it ever was. There are two classifications of method that are useful in connection with indirect labor standards. These are

1. Methods that can be prescribed more or less exactly by management.

2. Methods that cannot be prescribed by management.

The latter classification, which is the one that gives the greatest difficulty, prevails in much maintenance and machine repair work. At the outset of a job, no one can say with exactness what must be done to complete it. If a machine has broken down, the trouble must first be located before it can be corrected. Not knowing what the trouble is, it is not possible to predict the corrective action necessary. Or if a pipefitter must replace a section of leaky pipe, it is difficult to predict in advance how rusty the old pipe joints are and what motion patterns he will have to use to dismantle the pipe. On work of this kind, the method must in large part be determined by the worker himself.

On most other kinds of indirect labor, management can establish with reasonable exactitude the methods it wishes to have followed. In many cases, however, it does not do so. It hires people who claim some degree of familiarity with the work they are to do and lets them decide how they are going to do it. Or management relies on the foreman to explain the methods that are to be used without first determining either if the foreman knows the best methods himself or if he is capable of teaching them if he does. It is small wonder, therefore, that the methods engineer who brings to bear on indirect labor operations his analytical methods study procedures is almost always able to develop much better methods for doing the work than have been used up to that time. To establish standards before the methods improvement work has been done will not only be foolish because of the cost reduction opportunities that will be missed, but will probably also be fatal to the success of the standards installation. Once standards have been established, the workers themselves will begin to study methods, particularly if incentive wage payment is used. They will develop improved methods in some cases which

will permit them to make earnings out of all proportion to the effort expended. More serious than this, however, is the fact that it will be possible to improve some jobs more than others. Thus inconsistencies in earnings will result which in all probability will cause serious labor relations problems and may ultimately force the whole installation to be abandoned. Even if the standards are used only as a measure of performance under a measured day work plan, if the effort required to attain an acceptable performance is not fairly consistent from job to job, trouble will in all probability result. From every standpoint, it is essential to study and improve methods before standards are established.

When good methods have once been developed, they must be taught to the workers if they are to use them. This seems self-evident, perhaps as we calmly analyze the problem today, yet one of the areas most neglected by management is the area of operator training. Just recently we observed a case where it took two operators two weeks to do a certain job. Analysis showed that they could have done the job in 4 hours if they had known how. But they didn't and no one showed them. The foreman merely assigned them the job and left them alone. He probably did not know too much about it himself, for the fact that it took two weeks to do the job did not seem to disturb him. The men had to cut and try, experiment and fail over and over again until they finally got the job done. It must have been frustrating for them. It was certainly expensive for the company. Yet the whole incident would have passed unnoticed if the work had not happened to be under survey at the time it occurred.

This case may be unusual in the amount of its inefficiency. But it is by no means unusual to find indirect workers who have received practically no training on the work they are doing. By neglecting this area, management is passing up an opportunity for making a major improvement. Training procedures have recently been developed which not only impart skills and "know-how" effectively but which also deal with attitude development or what we might call the "want to" factor. The results which they get are not only gratifying to management, but they are welcomed by the workers as well.

Not long ago we were developing a training program for a group of maintenance workers. Under what we call the Master Training Concept or MTC, we always encourage the trainees to help to develop the program and to help decide on the areas in which they feel they need training. This particular maintenance group was composed of men who had 10 years or more of seniority. Yet after an exploratory discussion, they agreed that they first needed training in the correct use of such tools as the hammer, the screwdriver, the file, and the hacksaw, before going on to the more intricate phases of maintenance work.

The management of this plant was somewhat surprised at first to learn that their experienced men felt this elementary training was necessary. As they analyzed the matter further, however, the reasons for it became apparent. The company had never done any maintenance training of any sort. Their practice was to hire new men as helpers and put them with the more experienced men. The more experienced men were supposed to do the training. But since no one had ever trained them, they themselves did not understand the work too well. When they finally had the opportunity to participate in a well organized training program, they welcomed it with almost pathetic eagerness.

This same lack of training in correct working methods prevails throughout all areas of indirect labor. Even in the toolroom where journeymen toolmakers are employed, we often find a decided lack of understanding of correct feeds and speeds. After training has been given and the machines are run at the feeds and speeds of which they are capable, a marked increase in production inevitably results.

So when we think of Taylor's definite task and definite manner, let us never forget that the definite manner must be taught. Taylor never did. He patiently and painstakingly worked with people until they knew exactly how he wanted the job done. Only then did he apply his standards and incentives. Others who have attempted to follow Taylor have not been so patient. They have wanted to get results overnight. They still do. When our article on Universal Maintenance Standards appeared in FACTORY last November, it mentioned the fact that we have developed over 125 maintenance time formulas. We were deluged with inquiries about how these formulas might be purchased. The balance of the article which carefully described the organization work, methods studies, and training activities which must precede the introduction of standards was passed over by those who were seeking quick and easy solutions to their problems.

Taylor warned against this way back in 1903. He said in his paper "Shop Management"

> "Another important factor is the question of time. If anyone expects large results in six months or a year in a very large works he is looking for the impossible. If anyone expects to convert union men to a higher rate of production, coupled with high wages, in six months or a year, he is expecting next to an impossibility. But if he is patient enough to wait for two or three years, he can go among almost any set of workmen in the country and get results."

It is true that our methods engineering techniques have been considerably improved since Taylor's day and that we can now do most phases of the work more quickly than was possible in his time. Nevertheless we cannot short cut any of the steps indicated by his formula if we expect to obtain results of lasting value.

So we come at last to the final step in Taylor's formula, the definite time. Although this is the step which is the title of this paper, it is impossible to deal with time intelligently until we have pinned down the factors of organization, methods, and training quite firmly. When this has been done, the problem of establishing time even on the rather irregular low quantity work that is usually considered as indirect labor is not particularly difficult.

The tools used for establishing standards for indirect labor are the familiar work measurement tools of the methods engineer--time study, predetermined motion time standards, work sampling, and time formulas and standard data. The factors which determine how these tools will be used are the repetitiveness of the work being studied, whether or not the method can be established in advance by management, and whether the element sequence is regular or irregular. A few examples will show how this works out.

Toolmaking is usually non-repetitive work. It is similar to the work done in job shops except that the precision required is usually greater. The methods by which any tool will be made can be predetermined with reasonable exactness. The element sequence is regular, that is to say the order and frequency in which various motion groups are used is quite consistent from job to job. The establishing of time standards, therefore, presents few if any problems that are not encountered on production work. Time study and/or predetermined elemental times may be used to measure the elements of the work, and work sampling may be used to determine the allowances which must be added for fatigue and personal, unavoidable, and special delays. The time data thus gathered must be put together into time formulas or sets of standard data. Because of the small quantities involved, the formulas must be carefully designed for ease of application. Although it requires a first-class experienced methods engineer to develop standards for toolmaking, the work involves no problems which have not been met and solved many times before.

Receiving, storekeeping, and shipping involve somewhat different problems. If the plant is a mass production plant, these operations become highly repetitive and are very little different from a work measurement standpoint than the direct

labor operations. When the plant produces a variety of products in quantities ranging from low to medium, however, the work measurement problem becomes more complex. The methods used can be predetermined with reasonable exactness, but the sequence of elements is decidedly irregular. Indeed, it is so irregular that it was thought for many years that it was impossible to establish accurate standards for it. Standards based on such over-all units as pounds of material handled, carloads shipped, and the like were tried, but where the work was of highly variable nature this did not work out well. The most successful approach has been to measure the individual work elements, to develop time formulas, and to devise a means for quick and inexpensive application.

Although the elemental times for performing receiving, storekeeping, and shipping operations can be measured by time study, the use of predetermined elemental times such as those provided by the MTM procedure has been found to be particularly advantageous. When more than one methods engineer is used to collect time data by time study, the problem has always been to get them to use the same elemental breakdowns. If the beginning and ending points used for each element by each methods engineer are not exactly the same, the data they collect may be practically valueless. When a predetermined elemental time procedure such as MTM is used, this problem disappears. With every motion identified and recorded, the grouping of motions into elements can be done at any time and in a uniform manner.

In addition, where work is of an irregular nature, it may be difficult actually to observe every element of the work in a reasonable length of time. Some elements are used infrequently, and the methods engineer may have to wait for some time before he gets the chance to time them. If he knows what the elements are and can visualize how they will be performed, it is a simple matter to determine the time for performing them with MTM. Experience has shown, therefore, that it is considerably quicker to develop elemental time standards for receiving, storeroom, and shipping activities with MTM than it is by time study.

When the elemental times are available, it is often a considerable problem to determine the frequency with which each element occurs and to develop time formulas from weighted averages of element groups which will yield standards of satisfactory accuracy. The time formulas themselves must be so compiled that they can be applied quickly by clerical personnel. The most successful installations call for establishing standards for each piece of paper handled such as received material reports, stores requisitions, or shipping orders. Since the volume of these papers is usually considerable, the standards application procedure must be quite simple. A setup that has proved satisfactory in many cases

is to have a female comptometer operator referring to tables of standard data compute the standard and record it on each received material report, stores requisition, or shipping order handled by the group she services. When the work has been completed, the group leader turns in the papers to a payroll clerk who adds the time standards recorded on each paper to determine the total hours earned. By comparing these to the total hours worked a measure of performance is obtained. This arrangement requires the daily development of time standards, for it is impractical to attempt to record and reuse the individual standards since the same quantities and groupings of parts or products seldom repeats. The increased production that results from the measurement and control of receiving, stores, and shipping work, however, is always much more than enough to pay for the additional clerical cost of administering the plan.

The approach to the establishing of standards for janitor work is similar to that just described, except for the problem of application which is usually simpler. Standards are developed from elemental times combined and weighted in accordance with the frequency with which they occur. The major problem here is to determine when the work called for by a given standard has been performed satisfactorily. In other words, how clean is clean? The best solution varies with the conditions existing in the plant, but with proper study and analysis it can be developed.

Inspection, which is often classed as indirect labor, presents no unusual work measurement problems, but it is similar to janitor work in that it is somewhat difficult to determine when a satisfactory job has been done. Most companies who have measured their inspection work and have paid for it on an incentive basis report that the quality of the inspection work improves. Frequently a check is maintained by having random samples of inspected work rechecked by another inspector from time to time.

The measurement of the work performed by laborers, handy men, material handlers, and helpers is difficult only if the tasks they are required to perform are indeterminate. Before measurement can be undertaken, the tasks they are to do must be made specific. Thereafter the measurement problem is the same as for any other low quantity work where the method can be predetermined and the element sequence is irregular. The application problem, on the other hand, is likely to be quite difficult because of the variety of tasks done and the small number of people involved. Often the standards are more valuable for determining the number of people required for a given level of business than they are for the checking of individual performance.

I have left a discussion of maintenance standards until last even though this is one of the most important activities to

measure and control, because it requires a somewhat different approach than the other indirect labor activities. This is because, as I have already pointed out, it is often not possible to establish in advance the exact method by which any given maintenance job will be done. The conditions of the work are highly variable, and it is impractical to specify the exact motion patterns the maintenance worker should use. This does not mean that it is unnecessary to give training to maintenance workers. Far from it. But it is training in methods of handling the tools of their trade and in planning how to go about doing a job rather than training in the exact motions used in the performance of specific maintenance jobs.

Because methods vary so, it is impractical to attempt to establish standards which will be accurate for individual jobs. Instead we must turn to statistical concepts for a solution to the problem. Instead of saying that a given job should be done in say 118 ½ minutes, we can say that the job should be done in from 105 to 140 minutes with the chance of being right at least 9 times out of 10. This range of time is called a standard work grouping. In any given installation, standard work groupings are set up to cover all the maintenance jobs from the shortest to the longest. The range of time covered by the work groupings is long enough to make it easy for a man thoroughly failiar with maintenance work to place any given job in the correct group and short enough so that when the hours earned are compared with the hours worked over the period of a week or a pay period a reasonably accurate measure of performance is obtained.

This concept which has acquired the name of Universal Maintenance Standards or UMS solves the problem of standards application very nicely. Standards are quick and easy to establish. Indeed, they are so easy to establish that it is often asked if the same concept cannot be extended to other classes of indirect labor. It can, of course, but to us it seems that if it is possible to measure work accurately it is more satisfactory to both management and the worker to do so. Only when accurate measurement is impossible because it is not possible to standardize methods should statistical concepts be employed, at least at this time when so many people do not understand the practicality of statistical approaches.

In this discussion of indirect labor standards, I have assumed that the standards are to be used for performance control purposes. The standards may be used either under some form of measured day work or for incentive wage payment. Of the two, I personally favor the latter. Wage incentives, properly administered, are fairer to the workman in that he is given the opportunity to earn in proportion to his ability and application to the job. From management's viewpoint they result in higher production.

But note that I said when properly administered. There have been so many cases where wage incentive installations have been unsuccessful that prudent management will wish to consider carefully before embarking on a wage incentive installation. It requires considerable management skill to use incentives successfully. It requires proper training of all management and supervisory personnel who are the ones who will administer the plan on a day-to-day basis. It requires a certain tough mindedness on the part of management to resist the efforts that will most certainly be made from time to time to weaken the effectiveness of the plan by introducing provisions contrary to the principles on which incentive payment is based, as for example, the too free payment of average earned rate.

Above all, however, it requires the willingness on the part of management to have the installation made right in the first place. Management must have the patience to permit the necessary study of task organization and methods to be made first. It must resolve no longer to neglect the all important area of operator training. Only then should it expect to have standards established. Only then will the standards be satisfactory for wage payment purposes.

The measurement of indirect labor offers an unusually fruitful source of cost reductions. It can do much to enhance the competitive standing and the profitability of any company. But it can do these things only if the installation is made properly with full attention applied to the definite task and the definite manner accompanied by proper training. Wise management will insist that these precede the establishment of the definite time.

INDUSTRIAL ENGINEERING APPLIED TO RESEARCH

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Having recently become associated with the Army Ballistic Missile Agency, as the Chief of the Management Services Branch, I cannot speak with a great deal of authority about all the possible applications of industrial engineering to the research field. However, my past experience as the Director of the Ordnance Management Engineering Training Program and the consulting work that we did with many Ordnance installations throughout the country, has made me aware of some of the more important roles that industrial engineering can and does play in this field. My discussion today will center mostly around approaches to the initial phases of organizing the Ballistic Missile Agency and the role industrial engineering has played. In addition, I hope to point out some of the approaches that may be useful in the future when we become more intimately associated with the research activity in the laboratories themselves.

Industrial Engineering, or the management engineering field, as it is known in this Agency, is concerned with assisting managers in determining more effective methods of operating an organization. Regardless of the level of work performed by the industrial engineer, regardless of the level of the organization in which he works, and regardless of the complexity of the particular situation he is studying, there is a similarity in his approach to finding the better way or designing a work situation. Many of us have spent most of our time as industrial engineers studying situations which have strong likenesses in one plant with another and certainly one situation with another. We have become accustomed to almost automatically seeking facts in a uniform manner and evaluating those facts against well defined criteria with which we have been familiar many times in past problems. Our ability to synthesize a new or improved work pattern has in many cases followed the routine of a step analysis and evaluation of facts. In the manufacturing field, where there is reasonable process control and where the applications of methods and process study, time study and other means of fractionating a problem are well known, techniques have become an almost rote procedure. Perhaps the single greatest dissimilarity in the industrial engineering approach to research activity is the fact that there is no rote procedure or exact similarity in one work situation to another. The development of improved ways of organizing or performing work can be achieved only through our ability to apply our approach

as a scientific tool. In many cases, we must not only make an analysis of the situation itself, but determine what kind of an analysis will develop the facts in such a manner as to permit solution to the problem, or achieve established objectives.

Perhaps a description of the approach that is being used by the industrial engineers would be of interest to you from the standpoint of understanding how a systematic procedure is used in approaching problem solving. Whether we desire to improve or to design an organization, a procedure, the development of a policy, or the development of a work method, the scientific approach which is used by the industrial engineer, and his ability to communicate with other people in the organization at appropriate points in the development of the solution, is really the key to his success.

In formalizing this approach and in using it as a means of controlling projects in the industrial engineering department, the following phases are being used to guide the engineers and to provide means of evaluating their work. The journeyman level of industrial engineer must, of necessity, do a great deal of work on his own in gathering data in terms of an objective, evaluating that data and performing the proper synthesis of the new or improved way. The ability to properly supervise the industrial engineer depends to a large degree upon the ability of the supervisor to know enough about the project to recognize when his broader experience may be used fruitfully in the project as well as assure that the project is progressing satisfactorily.

The phases of projects are as shown on the following slide:

PROJECT CONTROL

PHASE 1 - Establish Goal
Make Preliminary Analysis
PHASE 2 - Analysis
PHASE 3 - Evaluation, Synthesis
PHASE 4 - Test, Trial, Implementation

To further describe these four phases, I will show a slide of the items which are considered under phase #1.

PROJECT CONTROL

PHASE 1 - Establish Goal

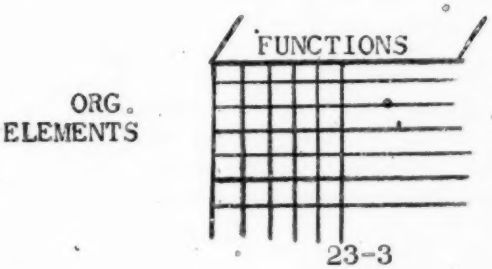
A. General goal in terms of overall achievement.
B. Specific goal in terms of actual savings or other achievement.

C. Preliminary analysis to determine:

1) Time to complete study.
2) Facts to be gathered.
3) Cost and time to make changes.
4) Anticipated personnel moves.
5) Current investment in skills and equipment.

Thus, we see that at the conclusion of phase #1, it is necessary that the engineer have developed his objective and his approach in enough specificity to permit the beginning of the gathering of data. In some rare instances, this first step may be a matter of form, but in most cases this is a well defined step. The desired goal, or achievement, must be fully agreed upon by all persons concerned. This must be fully understood by the industrial engineer so that his analysis of data will not be subject to his own intuition or his own insight into the problem but will more closely fit the needs of the manager, himself, in approving or or deciding to use the results of the staff study. No such assurance can be gained where an aura of mystery surrounds the data gathering stage and the eventual synthesis of the new or improved pattern.

One of the first industrial engineering approaches to the organization has been the design of the organization structure itself. This involves the relationship of the staff and line organizations and the organization of each subordinate division. This has been of extreme importance in this organization because of the unusual nature of the product and the absence of the usual criteria of effectiveness. Therefore, the effective organization in this case becomes a complex study of the authority and responsibility of individuals and departments and the relationship that these departments have with one another in the carrying out of the various functions. A similar approach to the linear responsibility and authority chart as printed in a past issue to Dunn's Review has been used for the overall organization design. This has been used primarily to achieve some perspective in the assignment of functions and activities to elements to the organization within the desired relationships as established by the Commanding General. As each element of the organization grows and develops its working patterns, they are continually checked with the overall organization design as portrayed in the relationships shown in the accompanying chart.

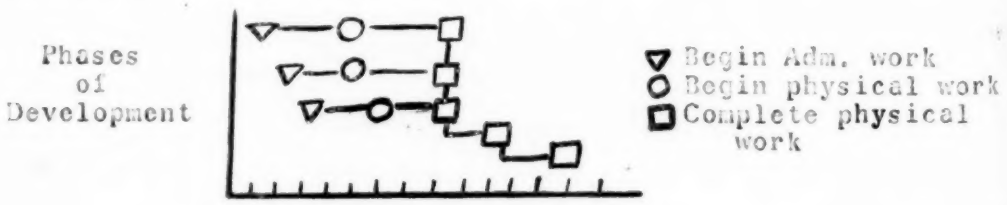


The major difficulty in approaching the design of an organization of this type, is the absence of the usual criteria of effectiveness or the objective. In this case, the objective can be more closely defined as achievement of full potential of the personnel and facilities available to the organization. This cannot be stated in terms of other than what is felt by all managers of the organization as being within reach in terms of research and development. In describing the relationships of the organizational segments, the categories as shown in the next slides have been used. These are similar to those shown in the article referred to above, but are somewhat different to allow for the specific application in this case. You will note that these definitions show the manner in which communication within the organization must be developed. As a result of this overall design, the next approach will be to develop procedure and policies necessary within each function.

Each staff and line function must then develop its communication system; policy, procedures and other directives.

In the effective operation of any organization is the coordination of all elements of production through a work planning and control system. In the case of research endeavor, this is a vital necessity since the carrying out of a program course of action must continually maintain its flexibility to permit the maximum achievement. Therefore, all progress and plans must be developed near a central organization who can, with perspective, observe the achievement of each element of research and its eventual transition into the production stage of manufacturing. This must be so designed to permit a central view of all operations with communication down to the lowest element with sufficient degree of sensitivity to change the course of direction of the whole when required, or to coordinate the performance of subordinate research endeavor.

The planned phases of work in the development of a missile, with the improvements that have been obtained through previous development and continued research, can be fairly accurately predicted. However, this may be considered to be more of a target by which time another missile with its accompanying improvements will be fired. Such a chart, which resembles the lead-time chart of any production activity, is shown on the accompanying slide:



However, the system of communication which must be devised, must provide the means by which adjustment in any phase of the development of any element of the total missile can be effectively and economically achieved. This must be seen in perspective by a central organization, as was stated above, but must not burden the operating elements with the need for reporting and supplying data continually. Especially is this true when one may be imposing a need that cannot be met by the working elements of an organization, and thus results in a synthetic supply of information and an overall ineffective control system. The ability of an organization of this type to fully program its activity and carry out a desired firing schedule, will be dependent upon the ability of the subordinate units to accurately reflect their situation in terms to be meaningful to a central and top level control. Not only must this be present in the system itself, but it is a method of operation which must be accepted by the organization as a whole. All too many times, we have heard the statements by many sources that research activity has been hindered, more than assisted, by the management experts who control the activity of the research scientists. This may be true in many instances, but is certainly not to be considered justification for allowing research activity to develop by itself or to expect it to be effective in achieving any desired goals without the means of effective communication and control.

It may be considered rather ridiculous by some to think that costs are important to research activity, especially when one considers that the cost of a program may be justified only in terms of how well it has served the country as a whole. However, costs are important in that there still exists a need for budgeting and there must be a means of comparing budget against accomplished plan. This must be in terms of items which are independently important in the research area. And the considerations must be given to money spent in the facilities which will be available to the organization in its continued program of research as well as the monies which will be expended in material and labor in achieving research progress or development progress through the firing of successively more accurate and effective missiles. From the lead-time chart which I have just shown you, lead-time controls can be, and are now being established, for use in integrating the entire system of control. These follow very closely the outline as presented by Dr. Lazarus in his previous approach. The detail which he has proposed has not been attained to date, but will be integrated in the system within a short time.

Another area of interest to the organization as a whole, which must be studied by the industrial engineering department, is the determination of the amount of manpower which will be needed to

operate the organization as well as a continued evaluation of the effectiveness of the group. The work of people in an organization of this sort covers the waterfront. All activities from pure scientific research to actual work with hands and machine tools are accomplished by people. The repetitive nature of work, the variability of work and the short run nature of work performed will, undoubtedly, prohibit the use of conventional techniques. Some accomplishments in this area have already been gained in other installations than the one in which I am currently associated. Perhaps a good example of the kind of approach that will be necessary is a very simple application of standards in an office situation. If we recognize that many organizations will not be performing work which is susceptible to establishment of standards, we will probably develop the need for a control over manpower in terms of both standard performance and perhaps nothing more than a record or justification of other work. This may even find itself in terms of allowances for non-standard work. In the particular case we are using for example, I will show you several slides which will indicate the approach which was taken to a clerical force of six people.

The nature of the work of this clerical force was similar to many offices in that all types of typing, collating, stenographic and clerical tasks were being performed. In addition, a library was being operated, a receptionist was doing these tasks in addition to the receptionist work, and one girl was maintaining a system of registering and controlling student enrollment. The first question that was asked about the work force was what percentage of work was spent in the various types of work that would lend themselves to standard setting and those that might be allowed as a flat percentage allowance and those that might otherwise be accounted for by maintaining records. The first slide shows the percentage of time in these various categories.

Category 1 - Productive Time - Standard
Category 2 - Productive time - Non-Standard
Category 3 - Personal Time
Category 4 - Interruption Time

The next determination was to find out of the standard work, which in this case appeared to be approximately 60% of the total time, could be placed under standard by using stopwatch time study or other approaches. It was found that the amount of tasks in this area was rather large since it covered a highly variable nature of work in that letters could be ¼ page, ½ page, full page, or more than one page, and other degrees of work which would necessitate the setting of several types of standards as well as maintaining accurate records of work performed. However, it was determined economical to establish standards by stop watch and predetermined time studies. In

some cases where the variability was such that we found standard elemental data economical, this approach was used. As a result of the study, allowances were made for personal time, interruption time (which was translated to be productive work which was not under the control of the operator), and productive on non-standard work which were items which were not susceptible to stopwatch time study.

The administrative controls were then established on the basis that it was expected that approximately 60% of all work would be performed under standard. The operator would receive full credit for standard minutes for work actually performed. In addition, she would maintain the elapsed time on work of non-standard category. This meant that she would get credit for the actual elapsed time on these duties. Since the total allowable time in this area was about 20%, it was felt that this was more in the form of an allowance than actually standard performance. The total efficiency of an operator was calculated on the standard minutes produced, the elapsed minutes of non-standard time produced as opposed to the amount of minutes during the day available to her. This excluded personal time and interruption allowance. Records maintained under this system have necessitated a very small amount of time on each operator in maintaining daily records. It results in approximately ½ hour a day of the Office Manager in tabulating the total results, but gives a complete picture within the limits of the system of performance and, naturally, translation to required manpower needs for the office.

The administrative control over manpower in activity of this nature will probably resemble this system just described. There is probably a question in everybody's mind concerning the type of labor controls over research activity itself. Here I think we have to evaluate performance with a much different concept than is typical. We are using the talents of a scientist, a man who is stimulated to think in terms of the objectives he has to reach and whose success and performance will be measured by his ability to use his thinking and resources to the best advantage. There can be no standard as such over such an activity, but there may be coordination over the achievement of his work and the success of stages of achievements through which he may go in reaching its immediate goals. However, the actual amount of people who could be considered in this category are perhaps not as great as we may think in most of our research organizations. We must supply several kinds of service and support to the basic research effort. These, to achieve their full measure of success, will probably be more easily adapted to standards of performance. Our manpower needs in this area and the amount of difficulty that a

research individual must expend in coordinating the efforts of people who service and supply him, will be a big determinant in the type of manpower controls exercised. So to sum up the area of manpower controls, there must be a combination of administrative controls which will depend upon several means of measurement. These measurement devices and the method in which the controls are exercised must be in terms of their support and service to the basic research effort, as well as some goal establishment for the research effort itself with guide marks along the road toward immediate goals.

In summary, the major areas of interest in the industrial engineering field in this area of research are as shown in the accompanying chart. I have discussed most of these in detail with the exception of description of some of the types of projects which may be assigned to industrial engineering. These, I feel sure, will continue to be the type that we normally encounter in any activity. A problem will be described, a ready solution will not be available, therefore, an objective method of fact finding, evaluation and synthesis must be employed.

The industrial engineering effort will undoubtedly be an important contribution to the success of a primarily research activity as it has been in many of our industrial activities. There are perhaps more precautions in this area than we normally find in the industrial area, that must be observed if we are to achieve full success. I say this to encompass the whole field of research where many industrial engineers have found frustration and sometimes rejection at attempting to supply their services in an area which is not susceptible to any typical approach. Here the industrial engineer must be truly creative in his thinking, and broad in his perspective in achieving results. You must recognize that the success of industrial engineering is not dependent upon excessive controls, but upon establishing a flexibility of operations within which the solution of many problems may be sought.

MAN AS A LINK IN COMPLEX MACHINE SYSTEMS

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During the last war, many complex machines and machine-systems were devised and put into use. They were not always successful, and not because they were poorly conceived or badly constructed. Very often they failed because they demanded more of human operators than human operators could supply. Personnel selection techniques, which were developed to a fairly high degree between the wars, were taxed to the limit to provide the kinds of skilled operators that the new weapons required. One of the major difficulties arose from the fact that the same general abilities were required of operators of all of the new hardware. They demanded a fairly high level of intelligence, some aptness for things electrical and mechanical, as well as some training along those lines. Needless to say, there weren't enough of the right kind of people to go around. Training procedures were slow and costly, likewise. It early became evident that the situation could be eased somewhat if the man's role in man-machine systems were carefully scrutinized with the view in mind of simplifying his task. It was thought that if machines could be designed by men, they could likewise be designed for men, and in so doing, that is, by taking advantage of man's inherent capabilities, less time and effort would have to be expended on his training and in cleaning up after his mistakes.

Since the war the problem has become, if anything, more acute. As the tempo of all living increases it becomes imperative that we utilize every advantage that man has to offer us, and that we force on him as few handicaps as possible. Whether we like it or not, man is here to stay, and for a long time to come he will continue to be a most important link somewhere in the chain of every machine system. After all, when you think about it, he's not such a bad thing to have around. Where else can you find a combination of servo motor and computer that is cheap to maintain and can be mass produced by relatively unskilled labor?

1/ The speaker wishes to thank the Department of Psychology of The Johns Hopkins University, and specifically, Dr. A. Chapanis of that department, for use of the illustrations used in this talk. Much of the material contained herein is the result of work performed at The Johns Hopkins University under contract with the Special Device Center of the U. S. Navy and the Office of Naval Research.

In considering man as a link in complex machine systems there are several levels from which the problem may be viewed. The first is a rather broad concept of man as a series or parallel link. Figure 1 is an example of man operating as a series link. Here the radar operator serves as a link between the radar itself and another man. Data in terms of space coordinates are taken from the visual display and relayed by voice link in this case to another man--a pilot perhaps, --to be used for navigational purposes. Figure 2 is an example of man as a parallel link. In this case, he is a pilot and he is in parallel with an automatic pilot. This use of an electro-mechanical system to relieve the human of a boring and routine type of operation is a recommended one. Now, of course, the danger inherent in using a man in one of these fashions lies in the fact that, unlike a machine that operates as it's designed to do--unless of course it breaks down--a man may change his mode of operation unpredictably and without warning. What was a moment ago a perfectly adequate series or parallel link may suddenly become, as in Figure 3, a closed link. Even psychologists haven't found the answer to this problem yet.

The analogy between man and a servo-motor has often been made and justifiably so, I think. Let us return for a moment to our airplane pilot who is such a good example of so many things. In essence, when flying his plane he is acting as a servo. Figure 4 will show you what I mean. He receives feedback inputs from his instruments, from the sound of his engine and from the general feel of the aircraft. He translates these inputs into corrective actions whose results are immediately fed back in return. The adequacy of man's transfer function within a servo system is dependent on what is expected of him. In hovering a helicopter, he does a remarkable job of maintaining a fixed position. If done by a computer, the solution of some 13 simultaneous equations would be required. Given the usual lag in control systems, the likelihood of his anticipating the results of his control movements so as not to overshoot is very remote. However, if "anticipatory" circuits were used in the system to display the effects of control movements in advance, his job could be performed much more adequately than at present. For these and similar operations, such as diving a submarine, it would be desirable to use electronic aids to integrate for him and use him as a simple amplifier in the system. It must be pointed out, however, that this is considerably more complex than it sounds, because the response characteristics of the vehicle vary as a function of the velocity and altitude. In fact, in some of our newer transonic interceptors, control responses may approach zero and even reverse themselves at about Mach 1.25.

Man's motor outputs appear to have a band width of about 10 cycles per sec. with a natural oscillation of about a half to one cycle/sec. Care should be taken to avoid putting him in a system with a resonant frequency which will be amplified by this 1/2 to 1.0 cycle per second oscillation. This is suspect in the tearing off of the wings in at least one of our new transonic experimental aircraft which apparently had a resonant frequency in this range.

If man is to be used in a servo-type system, then it were well to provide him with as much input information as possible. Figure 5 presents a summary of the desirable characteristics of a man-machine servo.

Auditory feedback from the sound of the motor combined with a visual indication and the feedback from the muscular response all contribute to more precise control than would be possible otherwise. A common complaint today comes from users of automobiles with servo-assisted equipment that fails to provide a proper amount of "feel" in the controls.

The second level from which the problem under discussion here may be considered deals with more specific things. To begin with, the human may be looked upon as a link between displays and controls. He receives an input from a display or a group of displays, he interprets the information provided and selects the proper response. Usually his response is made effective through some system of controls. Figure 6 shows in a schematic fashion one situation that is descriptive of what I have been saying.

It becomes evident at this point that the proper design of displays and controls is important.

From almost any standpoint you may wish to consider it, we obtain most of our information from the world about us through the medium of our eyes. This is true for the machine operators in industry, for the pilot of an aircraft in the military or for anyone engaged in the ordinary pursuits of everyday existence. For that reason, visual displays whose purpose is to convey information, are important whether they are for such specialized tasks as driving a truck, piloting an aircraft or controlling airport traffic, or for less specialized pursuits like advertising or education. If they fail to convey information because of ambiguity, illegibility or whatever cause, they may be art, but they are no longer visual displays in the sense that I mean.

In the main, industry and the military are concerned with displays for specialized tasks, and since they are usually visual displays, I intend to concentrate on that aspect of the problem today. These displays, very often, though not always, take the form of

dials such as speedometers, pressure gauges, altimeters and the like. Generally, it is important that the information they convey be readily interpretable -- speedily and accurately. Therefore, it is vital to know something about the perceptual capacities of those who are going to interpret them in order to design them so that they can be read quickly and without error.

Instrument dials, which are the type of display I want to talk about mainly, can be divided roughly into three categories. Figure 7 shows schematically what these three categories are. First, there are those that are used for "check" readings--they usually give "either"-"or" information and are used to tell an operator that something is "on" or "off" -- working or not working. Or they may be used as warning devices. Second are the qualitative instruments. These usually indicate the state of something with the addition of a directional component. Many dials designed for more quantitative purposes are often used by the operator merely for the qualitative information they provide. One example that I know of concerns the manifold pressure gauge and cylinder head temperature gauge in certain types of aircraft. Pilots report that their instruments give much more precise indications than they ever need or use. All they want to know is whether the readings are reasonable and to be able to see when they begin to go off. The third type of instrument is the most common one and the most important one, since it provides the operator with fairly precise quantitative information that can be vital to his needs in many situations. When dials of this sort have to be read quickly and accurately, their design is particularly important.

The next slide, Figure 8, shows three military equivalents of the kinds of dials I have been discussing. The "check" dial in this case is a bank of lights, the "directional" dial is an aircraft bank indicator and the quantitative dial is a radio compass used for navigation.

One important quantitative dial that is extremely important in airplanes is the altimeter. Failure to read this properly can lead to disaster. Some years back a survey was made of dial-reading errors among Air Force pilots, and one result of that investigation was the finding that the three pointer altimeter was about the most difficult aircraft instrument to read correctly.

Figure 9 shows clearly the conventional three-pointer altimeter and one type of reading error that is extremely common with them. A carefully controlled experiment with 97 experienced pilots and 79 male college students showed that in reading altimeter settings at rapid rates the pilots made errors of 1000 feet or more about 12% of the time and college students about 17% of

the time. As a follow-up, five different types of altimeters were designed and tested similarly. All five proved to be better than the one in use in terms of time taken to read and number of reading errors committed. I'm sorry that I don't have a slide to show you the five types of altimeters tested, but I can say that the instrument that fared the best--and this is not surprising, of course,--was a direct-reading counter. Mechanically, such an instrument is impractical to devise for that particular use. However, another instrument that was only slightly worse than the direct reading counter, was the combination of a single multi-revolution hand and a direct-reading counter. The altitude in thousands of feet was given by the counter while the single hand denoted the hundreds.

The development of such an altimeter that would operate directly on barometeric pressure proved to be not an easy matter. The first attempts were not altogether successful, since an absolutely foolproof instrument was required--one that could not become inoperative due to mechanical or electrical failure. Much time and effort (nearly five years' worth, in fact) have resulted at last in success.

This type of instrument is now being produced commercially and will probably supersede the conventional three-pointer type in time.

If you ever stopped to think about the design of instrument dials, you were no doubt impressed by the number of ways they can be varied. Size, shape, size of scale interval, type of scale-linear, logarithmic, etc.--type of lettering, type of pointer-- these are only some of the ways. The effect of all of these factors has been studied in more or less of a systematic fashion, and to review them all here would take more time than I have at my disposal. There are three that I do want to mention briefly, however. These are the effect of the size of the marked scale interval on accuracy of reading, how scale numbering effects the accuracy, and the effect of different dial shapes on accuracy of interpretation.

Figure 10 shows the three perceptual steps that are involved in reading a dial scale when interpolation between marked intervals is required. It is self-explanatory to a large extent. It doesn't take long to decide that the pointer is somewhere between 2.4 and 2.6. It takes a little longer to see that the pointer is between 2.4 and 2.5. Often this is enough accuracy to suit anyone, but occasionally it is necessary to interpolate a little more closely. The problem at hand then, is to know just how the distance between the marked intervals affects accuracy of interpolation. An experiment on just this problem

was performed and the results are shown in Figure 11. It is evident that for very small scale intervals the relative error is large, while the absolute error is small, and that as the size of the scale interval increases the relative error decreases until for a separation of 10 mm. it reaches a minimum and stays there. The absolute error, however, continues to increase. This relation holds, incidently, over a very wide range of dial sizes. The inference to be drawn from these results, then, is that no advantage, in terms of accuracy of interpolation, is to be gained from marked intervals larger than 10 mm, but that intervals any smaller are liable to result in an increase in the size of the error considered as a percentage of the marked interval.

Researchers in England some years back made a thorough study of the accuracy with which people could read dials with different numbering systems. No purpose would be served in giving you all of the detailed and complicated findings of that research, but Figure 12 presents a brief summary that will give you some idea of what was demonstrated. There is, of course, nothing very profound in what you see there, but one doesn't have to search far anywhere today to find scales that violate these principles. What this slide doesn't show, but what were also conclusions reached by this study, were (1) the fact that scale numbers that are decimals, as opposed to whole numbers, are harder to work with than those that are not, (2) the best scale numbers are whole numbers that are divisible by ten: 1,000, 100, 10 and so on. Whereas scale intervals in 4's are the most difficult, (3) that 8 and 16 scale units between numbered markers are hard to read, but 2 scale units between numbered markers are easy if enough room is left between the numbered markers.

Another important consideration in dial design is the shape of the dial. Shall it be circular, rectangular, semi-circular, or what? Figure 13 shows the results of an experiment in which 5 dial shapes were tested for single-revolution dials. In this research, observers were forced by appropriate procedures to read the dials very rapidly. It can be seen that by far the most superior display was the open-window one at the bottom where, out of a total of 1,020 readings, only 5 were in error. It should be pointed out here that the open window dial is not necessarily the best dial for all conditions. In situations where ample reading time is allowed, or where the scale or pointer is not static but is moving, other types of dials would give optimum results.

These few examples don't begin to tell the whole story of the problems that have faced and continue to face the human engineer in his attempt to make easier the lot of the man who is confronted with a complex interpretation task. If we have succeeded at all

in preventing the kind of situation that you see depicted in Figure 14, then our effort will have been profitably expended.

So much for the input side to our human link. Equally as important is the output or control aspect of the problem. If you want to convince yourself how vital that part is, all you need do is look into the cockpit of any modern commercial airliner. Air Force psychologists have been concerned with this problem for a long time and much useful knowledge has come from their researches and surveys. Pilot errors in one study were found to be caused by confusion of controls in many cases. Responsible factors were the crowding of controls and non-standardization of control shapes and locations from plane to plane. Another type of error resulted from the fact that sequences of control adjustments were too complicated and, in emergencies, improper sequences were used or portions of sequences were forgotten. Finally, reversal errors were frequently made. That is, a pilot moved a control in the opposite direction from that which he intended. Superficially, this might be considered the pilot's fault, but it has been established that there are "natural" directions of movement for controls and, under stress, people are liable to revert to these "natural" tendencies. If an important control is designed to operate in opposition to these principles, only trouble can be expected in the long run. In those cases where there may be no preferred direction or pattern of movement another principle has been shown to operate. It has a technical name which need not concern us here, but, in brief, a statement of the principle is this: If a new motor-coordination pattern is learned in the course of learning a new skill, and if, later, for some reason, that pattern has to be slightly altered to conform to a new development, then should an emergency arise, the tendency to revert to the earlier learned pattern is very compelling. I'm sure all of you have experienced the operation of this principle to some degree. How many of you have been embarrassed to find yourselves pumping air with your left foot the first time you had to make a sudden stop after getting behind the wheel of an automobile with automatic transmission? To give you another, and a personal example, when I first went to England some years ago, I was continuously reminded of the power of this principle by the English custom of driving on the left hand side of the road. Having become familiar with this phenomenon in my work, I was forewarned and so kept out of any serious trouble while adjusting to the new patterns. However, after driving around England for several months, I made a trip to Paris where I hired a car and proceeded to drive it out of the garage and up the left-hand side of the street to the horror of my companion in the front seat. That rattled me a bit, and since I was already under a great deal of stress getting used to a gear-shift lever that emerged from the center of the instrument panel and shifted inversely to anything that I'd ever seen before,

I was in a state of complete jitters when I reached the Champs Elysee. Whereupon, I promptly made a left turn up the left side of that frightening French speedway. Well, as you see, I survived, but there are those who don't. Many pilots who learned to fly in planes that had the flap controls on the right and the landing gear controls on the left, have never lived to regret the day that they transferred to a plane with the flap controls on the left and the landing gear controls on the right.

As in the case of visual displays, I can only give you here a very superficial glance at the sort of things human engineers are doing to improve controls. Figure 15 is a resumé of much work that has gone into establishing preferred directions of control movements. At the top the several arrows show the direction in which a control should be moved for the function that it is to serve. Thus, a toggle switch should flip up for ON, GO, or INCREASE, and down for OFF, STOP, or DECREASE. Similarly, levers whose motion is in the horizontal plane should go away from the operator for ON, GO, or INCREASE, and toward the operator for OFF, STOP, or DECREASE. At the bottom is shown the direction of hand wheel movement most suitable for use in connection with an associated visual display, when the display is to the right of the control and when it is to the left. In the case of the handwheel controls, clockwise movements should move displays downward if the display is to the right of the handwheel, and upwards if it is to the left. The reverse should be true of counterclockwise movements.

Another problem that arises when a control is used in conjunction with a visual display concerns the optimum gear ratio for the movement of an indicator. Experiments on this problem point to the fact that when speed is the prime objective the task can be broken down into three components. First is the reaction time--or the time that it takes to get moving. This turns out to be a constant factor. A second consideration is what may be called primary movement time--or the time required to move the indicator to the correct vicinity. The third factor can be termed secondary movement time or adjustment time, and, as you might expect, this is the time required for fine corrective movements once the indicator is in about the right vicinity. Figure 16 shows how these three factors contribute to alignment time as a function of the gear ratios used. Here you see that if a pointer is geared to move only a small amount for each revolution of a knob, primary movement time is long; on the other hand it is short if the pointer movement is large for each revolution of the knob. Secondary movement times, it appears, are almost the inverse of primary movement times. The best overall ratio occurs at that point where the sum of the three time components is at a minimum or about midway between 1 and 2 inches of pointer movement for each revolution of the knob.

Still another type of gear-ratio problem has to do with the mechanical cursor that is encountered on many remote plan-position radar indicators used with military services equipment. Figure 17 shows the time in seconds required to slew a cursor through 15°, 75°, 105°, and 165° using various gear ratios. It seems clear cut that for excursions greater than 75° there is an optimum gear-ratio of about 5 to 1. For excursions less than 75°, the optimum gear-ratio appears to be somewhat larger than that. However, on the basis of these data, it is possible to recommend a not too unhappy compromise at around 5 to 1, since the gain in time for higher gear-ratios and lower degrees of excursion is not appreciable.

The optimum rates of control movements are determined in part by such factors as the maximum rate of muscle contraction, the maximum rate of innervation and the effect of fatigue. High rates of movement are commonly required by handwheel controls. Winding movements are a combination of reciprocal movements properly distributed in phase. Their maximum rate is approximately half that of simple back-and-forth movements of similar amplitude. The rate that results in most accurate control depends on handwheel diameter, inertia, friction and other design features. Figure 18 shows how cranking speed is affected by crank radius and friction-loading of the crank. Two things are evident here. One is that for every crank loading there is an optimum crank radius, and second, that as the friction-loading of the handwheel increases, the optimum radius likewise increases slightly. Figure 19 is an illustration of the way handwheel tracking accuracy increases as a function of the speed of handwheel turning. This function was measured for a crank radius of 4.5 inches. The error was measured in terms of the time that would be required for the target to move from the point of aim to its actual position. As you can see, accuracy improved steadily with increasing handwheel speeds. This slide and the one just preceding it make a very nice picture and provide some fairly general principles that can be applied to the area of handwheel tracking.

Since confusion of controls has been shown to be one of the prime causes of errors particularly where pilots are concerned, much research has gone into ways of avoiding such confusions. Different methods of control coding have been extensively investigated and some general conclusions can be stated.

It has proven possible to shape code controls--that is, design knobs with different shapes that can be immediately discriminated even with gloves on. If some standardization were adopted, so that similar functions on different pieces of equipment had the same shaped control knobs, training problems would be easier and less confusion would result.

Extensive studies have been made on the ability of people to reach, without looking, and operate controls -- either beside them, above them, behind them, etc. If a high degree of accuracy is required, it is best to arrange the controls in a vertical row at shoulder level. A safe distance between these controls is 5 inches.

Color coding is another aspect that has been gone into very thoroughly. The number of discriminable colors, if one includes all hues with varying degrees of saturation and various degrees of lightness and darkness, has been judged to be 300,000. However, in the practical situation, the operator has neither the time nor the inclination to identify colors by comparison; rather he must be able to identify the colors in an absolute sense. Estimates of the number of such absolutely identifiable colors suggest that there are no more than ten or twelve where spectral hues are concerned. However, there are many disadvantages to using color for coding controls. For example, many colors already have meaning attached to them--red, green, yellow for danger, go and caution. And also the amount of illumination available and the type of illumination greatly affects the way colors are seen. These things are not always easy to control.

As I stated before, there is much more to the design of controls than I have been able to indicate here. Very important areas have not even been mentioned, but I hope, at least that some of the flavor of the work of human engineers has been imparted to you. By continuing effort, we hope to be able to increase the efficiency with which operators can perform their tasks and at the same time relieve them of some of the strain that they have often suffered in the past in trying to pursue their duties. If we can alleviate the plight of people in situations similar to that of the poor fellow in Figure 20, some good will have been accomplished.

I wish to point out in closing that too often, in the past, the human component has been overlooked in the original design. The engineer has taken advantage of man's flexibility to fill a function that could not be produced readily with an electronic or a mechanical component. The man has been put into the system as a glue to hold it together. At best, consideration of human factors has often been given a secondary role by most designers of equipment. This is not surprising since the same flexibility mentioned before has allowed the man to be used as a general purpose component.

Man can talk, push buttons, use handcranks or joysticks and many other things. All of these outputs are usable and have been used in man-machine systems. It must be remembered that

his motor performance characteristics vary considerably depending upon the mode of response. The design engineer can use these characteristics in two ways: (1) to provide those movement characteristics which are desired as input to controls and (2) to eliminate those movement characteristics which are undesirable.

Man has good long-term memory for generalized experience, but rather poor immediate memory for specific detail. His access time is slow compared to that of a computer but he is able to recall generalized patterns of previous experience to solve immediate problems. No computer can yet do this.

He is flexible and can do many things well if his limitations are taken into account. The machine should be used to relieve the man of as many routine jobs as possible, but the man should be used to supply judgments and flexibility of which machines are incapable.

Take advantage of the best the human link has to offer, whether it be the result of his perceptual acuities or his physical capabilities. Keep continually aware of the human factors involved in the design of equipment or systems in which the human is a link. Do not try to squeeze him in as an afterthought. Remember, the classification of a design error as an "operator error" is not a remedy-- it is an excuse.

I thank you.

24-12

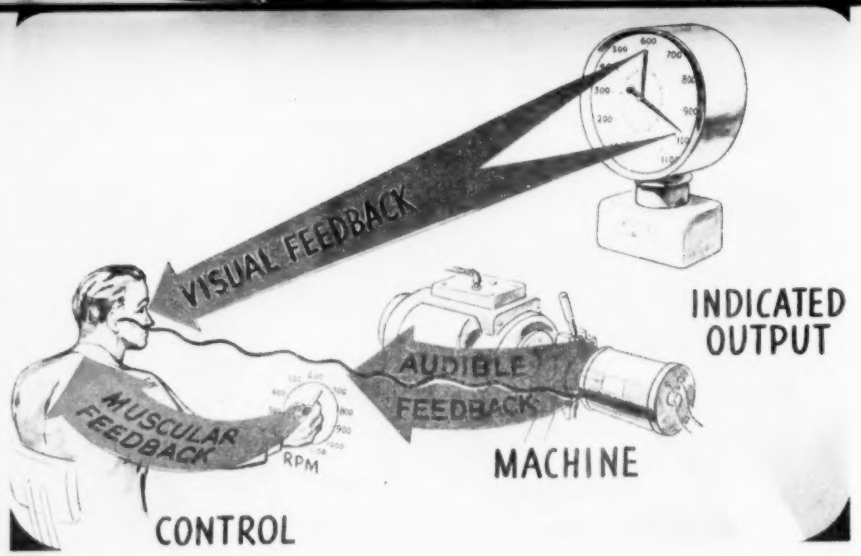
FIGURE 1

24-13

FIGURE 2

24-14

24-15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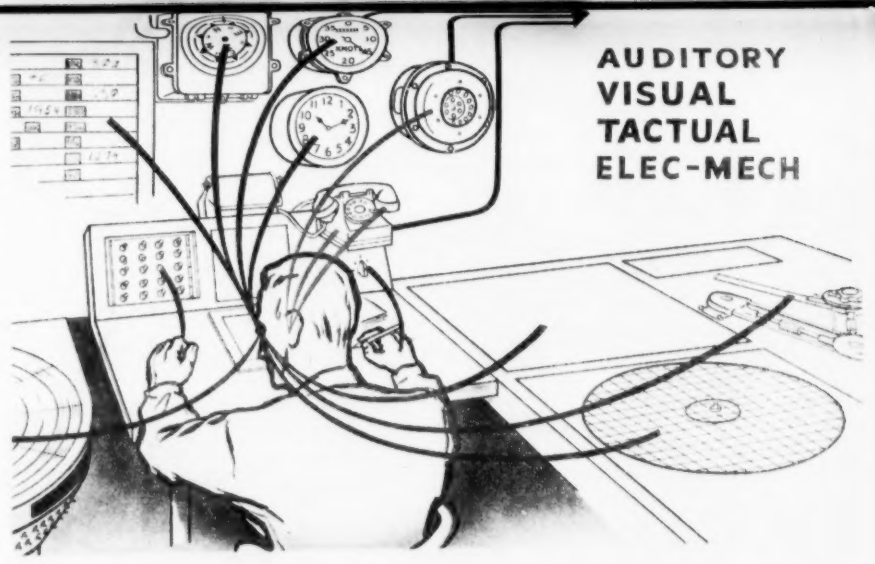
INDICATED OUTPUT
AUDIBLE FEEDBACK
MUSCULAR FEEDBACK
RPM
MACHINE
CONTROL


AUDITORY
VISUAL
TACTUAL
ELEC-MECH

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IGNITION
CHE
COOL NORMAL HOT
DIRECTIONAL
QUANTITATIV

CHECK
DIRECTIONAL

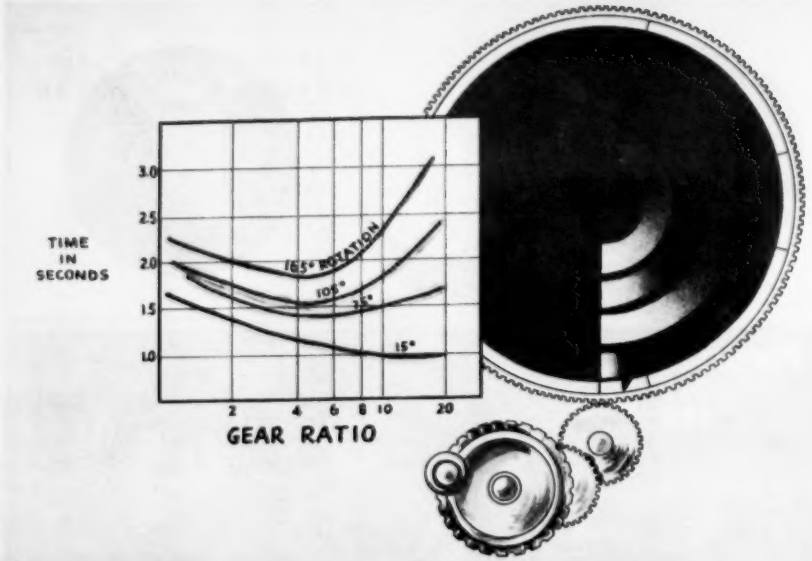


FIGURE 17

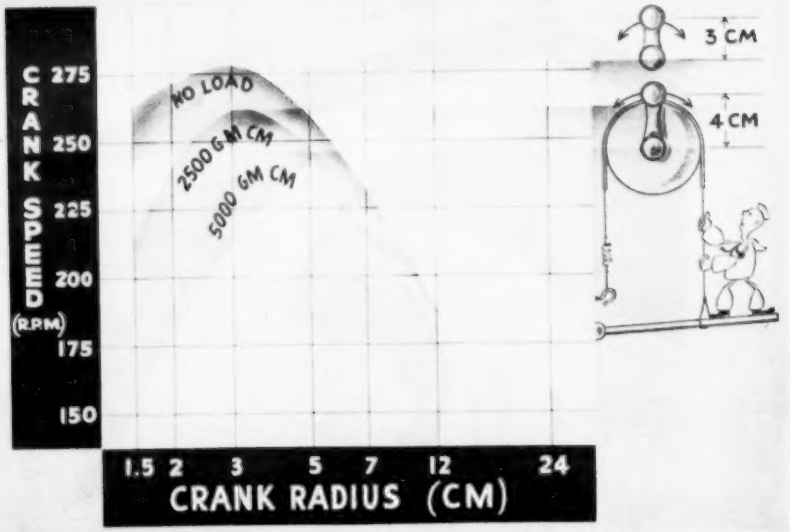
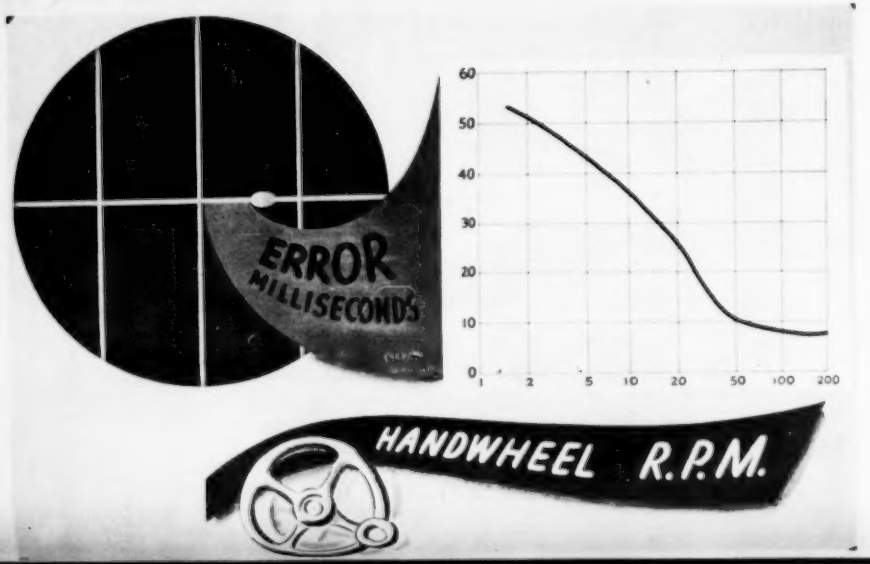


FIGURE 18



LINEAR DECISION RULES IN PRODUCTION AND INVENTORY CONTROL*

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I. INTRODUCTION

The expression "production and inventory control" covers a wide variety of problems in the operation of manufacturing facilities. We face questions of the following sort: Which of a usually large number of products should be made, when and how much? What raw materials and parts should be purchased, what components that may be used for several products should be made? How many workers should be hired, or laid off, this week or how much overtime should be authorized? What levels of raw material, work-in-process, and finished goods inventories should be maintained? How much should be shipped from the factory to the warehouses?

These are important questions, and they are often perplexing ones. Part of the difficulty arises from the fact that nearly every type of decision depends upon everything else. For example, steps taken to affect the level of finished goods inventories also affect the rate of production. The problem of designing appropriate scheduling procedures is greatly complicated by the fact that decisions need to be made in several stages of the procurement-manufacturing-warehousing-selling sequence. Even in a relatively simple situation we might have the following stages:

1. Procurement of raw materials and purchased parts,
2. Raw material inventory,
3. Parts manufacture,
4. Work-in-process inventory,
5. Finished goods assembly,
6. Finished goods inventory,
7. Shipment to district warehouses,
8. Warehouse inventory,
9. Sales to customers.

* Research undertaken for the project Planning and Control of Industrial Operations, under contract with the Office of Naval Research. Reproduction of this paper in whole or in part is permitted for any purpose of the United States Government. Contract Nonr-76001, Project NR 047001.

** The results reported in this paper are from joint efforts of Charlie Holt, Franco Modigliani, Herb Simon, and John F. Muth.

Our object here is to report some of the quantitative methods that have been developed in the last few years as possible solutions to some of these problems. Much of the basic research in this area, including the work at Carnegie Tech, has been sponsored by the Navy and Air Force.

In the course of later discussion we will first examine briefly the "classical" lot-size formulas and more recent developments for setting reorder quantities and protective stock when the rate of future sales is uncertain. The problem then arises: How can the inventory control procedures be reconciled with production requirements? We will then discuss methods of taking the costs of overtime work and labor turnover into account for the inventory decisions. A very useful method is what we have called "linear decision rules"; these rules or policies are so constructed that the sum of inventory, overtime, turnover, and other specified costs is minimized, even if future sales are not perfectly known. Finally, we will sketch the results of the application of this rule to a paint factory.

In order to gain perspective into problems of inventory policy, we might ask what are the advantages in -- or the reasons for -- holding inventories. There seem to be at least four:

1. Lot-size advantages: Saving of costs incurred for each lot that is purchased, manufactured, or shipped (for example, costs of setting up a machine for a production run).

2. Uncertainty advantages: Protection against a run-out when demand cannot be predicted exactly.

3. Smoothing advantages: Avoidance of factory overtime during peak seasons of sales, investment in excess capacity, and rapid fluctuations in production.

4. Price advantages: Price speculation in inventories, and taking advantage of quantity discounts.

Since the questions raised earlier ultimately involve weighing the costs against the gains of inventory holdings, we would expect that research directed at production scheduling should be applicable to that of inventory control. Until recently the relation between the two had hardly been recognized, and had been the object of separate research efforts. We will indicate later some methods by which at least some of the interrelationships had been handled.

II. INVENTORY REORDER POLICY

The earliest efforts, started over 30 years ago, in the mathematical formulation of inventory policy focussed upon the first advantage of inventories -- those of the lot size. What has been accomplished can be summarized under three topics.

Known future sales. In this case, the problem is that of determining a production (or order) quantity so that the advantage of spreading set-up (or procurement) costs over a large number of products is balanced against the costs of storing the resulting inventories. Suppose, for example, that the cost of setting up a machine for a run can be represented by the quantity C_F (the fixed cost). The cost of storing a lot of size Q depends not only upon C_I, the cost of storing one unit for a period of time, but also upon the rate of sales (assumed constant) which we will denote by S. The cost per unit of storing a lot of size Q is $\frac{1}{2}C_IQ/S$ (see Figure 1).

Consequently, the cost per unit of set-up costs and storage (which is sketched in Figure 2) is the following:

$$C = C_F/Q + C_IQ/2S.$$

How large must we make the lot size Q so that the cost expression above is minimized? The optimum value, say Q*, is found by setting $dC/dQ = 0$, from which we obtain the lot size formula:

$$Q^* = \sqrt{\frac{2C_FS}{C_I}},$$

and the average level of inventories would be the "half-lot" Q*/2. There are many variations to this basic cost model, but the square root formula seems to be a characteristic of these problems. For more detail on these relations, the reader is referred to Magee [16] and Whitin [24].

Unknown future sales. Introducing uncertainty into the lot-size problem generally complicates the analysis. This is so if the stock cannot be replenished almost immediately; for if the lead time on ordering were zero, it would be possible to reorder whenever the stocks are depleted. There is no chance of failing to meet customer requirements for the product. But the usual problem does involve both uncertainty concerning future sales in the presence of manufacturing or procurement lead times.

In this case, it will be necessary to carry extra inventory as protection against not being able to meet demands during the interval of time between the placing of an order and receiving the lot. It is usually the case that in the presence of both uncertainty and lead times there is some chance, however small, of running out of inventory no matter how large the inventory is. It is then necessary to balance the advantages of protective (or "buffer") stock against the costs of carrying this larger level of inventories. This balance can be carried out in one of two ways:

1. Assign a tolerable probability of inventory depletion, P_D, or

2. Place a cost C_D upon inability to meet customer demand.

The preassigned probability of a run-out, P_D, is often taken as the criterion for setting buffer stocks because the cost of depletion is rather difficult to measure. Normally, however, some estimate the coefficient C_D should be made at least as a check. It might represent only the foregone profit (price minus the variable cost) in not being able to meet demand, but usually there are other effects that should be taken into account (for example, the loss of repeat business). On the other hand, if the order can be backlogged and filled at a later time, then the cost may be considerably smaller than that indicated above.

An order rule must specify not only how much should be ordered, but also when the order should be placed. In the case of certainty the answer to the last question is unambiguous, but in the presence of uncertainty there is a range of alternatives characterized by the two extremes:

1. Order at the end of every T months. Usually called the order cycle or "tickler" rule, it specified that an order is to be placed at the end of the reorder period regardless of the state of inventories. Of course, the amount of the order will depend upon the level of inventories on hand and on order plus the expected sales during the coming period.

2. Order whenever inventories fall below a preassigned level. The "trigger" rule specifies that an order is to be placed whenever the amount of inventory on hand and already on order falls below the trigger level regardless of how long it has been since the last order has been placed.

In principle, the trigger rule requires lower buffer inventories because a run-out can occur only during the lead time. Run-outs for the tickler rule can occur at any time. However, the trigger reorder rule is often unsatisfactory in other respects, as we shall see below.

The state of inventories at any point of time for the trigger rule is sketched in Figure 3. As soon as the actual inventory reaches I_T, an order is placed for replenishment. The probability of a run-out, then, equals the probability that sales in the interval of length T_L months exceeds I_T. If $f(S)$ is the probability density of the sales rate, then the probability of a run-out and average sales rate would be respectively:

$$P_D = \int_{I_T/T_L}^{\infty} f(S)\, dS = 1 - F\left(\frac{I_T}{T_L}\right),$$

$$\bar{S} = \int_{0}^{\infty} S\, f(S)\, dS.$$

We will assume that depletion costs do not depend upon the length of time that the warehouse cannot supply a product, but only on the total amount that cannot be supplied (this would be approximately true if the only cost were that of a lost sale). Then the expected value of the run-out cost each time the trigger is hit is:

$$C_D \int_{I_T/T_L}^{\infty} (ST_L - I_T)\, f(S)\, dS$$

The expected cost of storing the extra inventory for the average period is:

$$C_I \int_{0}^{\infty} (I_T - ST_L)\, T\, f(S)\, dS$$

$$= C_I \left(\frac{I_T}{\bar{S}} - T_L\right) F\left(\frac{I_T}{T_L}\right), \quad \text{approximately.}$$

Minimizing the sum of the run-out and inventory costs (see Figure 4) as a function of the trigger inventory, with the aid of the calculus, we obtain the following equation which the optimal trigger level, I_T^*, must satisfy:

$$F\left(\frac{I_T}{T_L}\right) = \frac{1}{1 + \frac{C_I Q}{C_D \bar{S}}}$$

Since the factor $C_I Q/\bar{S}$ represents the expected cost of storing a unit for a complete order cycle, the expression $C_I Q/\bar{S}C_D$ is ratio of the cost of storing an item for a period to the cost of running out of that item. The probability, 1 - F, of running out of inventory should be a simple function of these relative costs. The optimal trigger level, then, may be found by inverting the function F. This may ordinarily be done numerically, and in some cases analytically.

It should be remembered, however, that the formula given above for finding the optimal trigger level is only approximately correct for several reasons: 1) some analytical approximations were used in the derivation of the equation for the optimum trigger level, 2) the order quantity was assumed to be given (actually Q and I_T should be determined simultaneously, although the "interaction" observed by Whitin [24] is ordinarily small), and 3) a very special form of the depletion charge was assumed. Nevertheless, the derivation indicates the nature of the considerations used in the formulation of more accurate rules. Of course the relevant question to ask is whether following this method of inventory planning will result in improvement of the operations, not whether it is the best that can ever be reached.

Recent developments. The models above for inventory control were concerned only with the costs of carrying stocks over one order cycle and the danger of run-outs at its end. More recently it has been recognized that the cost implications of current decisions upon subsequent periods are sometimes important. However, when this additional stipulation is made it becomes impossible to arrive at the decision for one period without considering the probability distribution of sales and the decision rules for these later periods. The essentials of this dynamic problem, applied to a simple case, are given by Arrow, Harris, and Marschak in [2] .

The papers by Dvoretsky, Kiefer, and Wolfowitz [10] give proofs for the existence and uniqueness of solutions to a mathematical statement of the inventory problem for a very wide class of situations, including the many-commodity and cascading-sequence case. Unfortunately, their theorems do not suggest practicable computational procedures and hence do not as yet give us decision procedures that one can employ in practice. Further important work on dynamic programming, yielding actual solutions in some special cases of interest, has been published by Bellman (see [4]).

In reviewing the methods for inventory control that have reached the stage of application, we must observe that they are subject to severe limitations:

1. By and large, only in the case of a single commodity do we have a solution we can actually compute. Although the standard lot-size formulas are relatively simple, not even present computing machinery is adequate for efficient calculation of some others.

2. Even in the case of a single commodity one can obtain a solution only under rather restrictive assumptions regarding future sales. Application of more general methods would require detailed knowledge of the probability distribution of sales for future periods -- knowledge which we do not usually possess.

3. The lot-size formulas, particularly if a "trigger" reorder system is used, are often incompatible with production operations. With such a rule, efficient sequencing of products is sometimes difficult or impossible, and it may be found necessary to break lots if two items produced on the same machine are "triggered" at the same time. Furthermore, a trigger system, without other controls, gives no guarantee that the overall production rate will be reasonably level.

Nevertheless, the work referred to above seems to be one of the important ingredients of efficient production planning.

III. AGGREGATE PRODUCTION RATE DECISIONS

The techniques to be reported in the remainder of this paper for resolving some of these difficulties were developed in the context of a specific industrial problem: to schedule the production in a paint factory of several thousand items for delivery to warehouses. The items are held in stock and delivered to the warehouses on demand, warehouse demand being based on rather widely fluctuating sales to customers. The product is manufactured by a batch process, with a fairly wide range of possible batch sizes. Moderate economies are obtainable from running large batches, and from proper scheduling of the product sequences; but within limits, manufacturing cost depends more on aggregate production than upon the exact product mix.

As a first approximation. we have assumed that the costs to be minimized can be divided into two independent parts:

1. Costs associated with aggregate monthly production and work force level, and

2. Costs associated with the product mix.

Although there are undoubtedly some interactions between these types of costs, it is believed that in many practical situations the interactions are small and can be ignored. In this section we will consider the first of these.

Sales fluctuations and stable production. In the long run, total factory production must equal total warehouse orders, but in the short run considerable differences between the two will be taken up in finished goods inventories at the factory. That is,

$$I_t - I_{t-1} = P_t - O_t,$$

where I_t represents the level of finished goods inventories (less backlogs) at the end of the t'th month, P_t is the production rate during the period, and O_t is the rate of orders coming in from the warehouses. If long-run demand were known with certainty in advance, then by using the calculus of variations, it is possible to determine a pattern of factory production that is optimal (in the sense of minimizing the total cost for the known demand). However, in actual situations estimates of future demand are subject to substantial forecast errors.

Although in the long run, the production should be equal to the warehouse orders, it is usually advantageous for the factory to level the rate of production to filter out much of the short-term fluctuations in the rate of incoming orders. In the language of servomechanism theory, a rule for scheduling production should have the characteristics of a low-pass filter, i.e. the rule should adjust production to changes in orders from one year to the next, but ignore seasonal and erratic month-to-month fluctuations in orders within the year. We have found that, in at least one specific application involving a large seasonal component in demand, a rough technique for taking out the seasonal fluctuations proved satisfactory when combined with a low-pass filter rule for adjusting to forecast errors. The decision rule is described by the following equation:

$$P_1 = \bar{O} - .20\ (I_o - I_c),$$

where P_1 is the planned production for the next month, $\bar{O}$ the

average monthly sales for the past twelve months, I_o the inventory at the end of the preceding period, and I_c is the "normal" inventory (this would be the "half-lots" and "buffer" stocks previously described).

The first term, $\bar{O}$, combines a simple forecast of orders (this year is going to be like the last) with an elimination of the seasonal variation. Previous errors in forecasts would show up in the deviation of the actual inventory I_o, from the desired level, I_c. Corrections for forecast errors will be made slowly so that the rate of production does not change much from one period to the next.

The decision rule above can be shown to have rather desirable characteristics by comparing the performance of the paint factory if this rule were followed with actual production rates. The rule leads to no crises or disasters, and appears to operate better (giving smoother production and lower inventories) than unaided judgment.

We would not like to leave the impression that this rule solves the production rate problem. But it does illustrate the point that even a fairly crude application of theory appears to lead to a procedure of definite practical utility. It is reasonable to ask at this point what further steps that may be taken to improve the rule so it can be said to have, in some sense, optimal properties? It is possible to tie this general line of reasoning more closely to the costs of plant operation, and to include another highly important decision: the size of the labor force. We will first examine the following costs which appear most important in the problem of short-term production planning for the factory in question: 1) inventory carrying and run-out costs, 2) costs of overtime work, and 3) the costs of hiring and laying-off employees.

Inventory and run-out costs. In formulating this part of the cost function we will assume that the inventory and back-order position of the factory at the end of each month is representative of the average inventory and backorder positions during each month, and may therefore be used to estimate the relevant costs. The lot size formulas of the preceding section may be used to estimate 1) the optimum aggregate level of inventories and 2) the cost of deviating from the optimum. By adding half the order quantity and the buffer stock, we obtain the average inventory for each product. The sum of the average levels for all products gives the optimum inventory for the entire factory.

The cost of inventory storage and run-outs as a function of aggregate net inventories (inventory minus back orders) may be

represented as is shown in Figure 5. The costs for a low level of net inventory are largely due to not being able to supply certain items on demand, while the costs for high levels of net inventory are almost entirely that of storage (deterioration, interest on investment, etc.). The low point is a function of the rate of sales. It should be noted that the costs of an aggregate level of net inventories is a function of the policy that is used in allocating the total among individual products. If the allocation policy is poor the curve would be shifted upward because some items would have large surpluses (thereby incurring storage charges) while many other products would be out of stock (and hence incurring depletion costs).

The dotted line in the figure represents the quadratic approximation to the original cost function. It may be written as

$$c_7 \left[I_t - (c_8 + c_9 o_t)\right]^2$$

where c_7, c_8, and c_9 are coefficients which depend upon the costs of storage, reordering, and depletion as well as the average rate of sales. The reorder quantities and trigger inventory levels are also implicitly included in the expression above since they are functions of the same cost coefficients.

Overtime costs. If order fluctuations are absorbed by increasing and decreasing production instead of inventories, then either 1) overtime and undertime costs or 2) hiring and firing costs will ordinarily be incurred.

The cost of overtime depends on two decisions, the size of the work force, W_t, and the aggregate production rate, P_t. The simplest form of this cost relation is shown in Figure 6. With a given work force and an average worker productivity, k (gallons per man-month), kW_t is the maximum number of units that can conceivably be produced in a month without incurring any overtime. Because of fluctuations in the productivity relation, however, the cost of overtime will ordinarily be somewhat higher. Since workers and machinery are somewhat specialized in their skills, it is therefore likely that a small increase in production would require only a few more hours in bottleneck functions. As production is increased further, more and more employees are required to work overtime until the entire work force is doing some overtime work.

The dotted line of the figure approximates the expected cost of overtime as a function of the work force at the end of the

period, W_t, and the rate of production for the period, P_t. The equation of the quadratic is:

$$C_3 (P_t - C_4 W_t)^2 + C_5 P_t - C_6 W_t.$$

As production exceeds that normally allowed by the existing labor force, the expected value of the overtime costs increase. Actually, a more complicated and perhaps more rigorous justification for this cost function may be constructed, but the argument here conveys at least the essential points.

Regular payroll, hiring, and layoff costs. Fluctuations in orders from the warehouses may also be adjusted to by increasing or decreasing the size of the work force, and if this alternative is taken, the following costs are affected: regular payroll, hiring, and layoff costs. First of all, as workers are hired, the firm is committed to pay the employees regular time wages for the entire month. This cost may of course be represented by the relation

$$C_1 W_t.$$

However, the coefficient C_1 does not necessarily represent the average wage rate; it should, instead, reflect the wages of those individuals who will possible be laid off or hired (that is, it would ordinarily be somewhat lower than the average).

The other labor costs mentioned are associated not with the sizes of the labor force, but with its changes. The cost of hiring and training people increases with the number hired, as is indicated by Figure 7. The cost of laying off workers arises from terminal pay, reorganization, etc., and rises with the number of workers laid off. Again, the dotted curve in the figure is a quadratic approximation to the original function which will be used in further stages of the analysis. The quadratic may be written as follows:

$$C_2 (W_t - W_{t-1})^2.$$

Whether these costs actually rise at an increasing or a decreasing rate is rather difficult to determine. It can be argued that reorganization costs are more than proportionately larger for large layoffs than for small layoffs; and similarly the efficiency of hiring, measured in terms of the quality of the employees hired, may fall when a large number of people are hired at one time. If this argument holds, then the quadratic

approximation is especially suitable. But if it does not hold very well, then the range of approximation will be somewhat limited. Nevertheless, the real test of the usefulness of this assumption is whether the scheduling rules that can be derived from these assumptions lead to an improvement in scheduling operations.

The total cost function. Having examined the individual cost components (inventory, overtime, regular time, turnover) we are now is a position to put the pieces together as a criterion for an optimal scheduling decision rule. It is not sufficient, however, to consider the costs incurred in a single period of time, because the production and work force decisions taken at the present affect the costs in future periods. Because of this reasoning, the objective is to plan for the present time, taking into account the future costs insofar as they are affected by the actions of the current period. The cost function that should be used as the criterion for the scheduling decision is the sum of costs over several periods in the future. We have as the relevant cost function:

$$C_N = \sum_{t=1}^{N} \left[C_1 W_t + C_2 (W_t - W_{t-1})^2 + C_3 (P_t - C_4 W_t)^2 + C_5 P_t - C_6 W_t + C_7 (I_t - C_8 - C_9 O_t)^2 \right],$$

the sum of the components previously presented. The two decision variables are the production rate and level of the work force. The inventory is not an independent decision variable because of the relation:

$$I_t - I_{t-1} = P_t - O_t.$$

The object then is to choose P_1, P_2, P_3, ... and W_1, W_2, W_3, ... in such a way that C_N is minimized. P_1 and W_1 will be the decisions taken in the next period of time. Planned future rates of production and levels of the work force may be revised in the light of information that becomes available later.

The cost function above may be applied to various specific problems simply by using the appropriate numerical values for the cost parameters C_1, C_2, ..., C_9. We shall not discuss here in more detail the ways in which these parameters may be estimated. Our experience indicates that estimation is feasible, and, moreover, that fairly substantial errors of estimation cause only moderate departures from optimal behavior.

The numerical values for the paint factory which we have studied are as follows:

$$C_N = \sum_{t=1}^{N} \left[340\, W_t + 64.3\, (W_t - W_{t-1})^2 + .20\, (P_t - 5.67\, W_t)^2 \right.$$

$$\left. 51.2\, P_t - 281\, W_t + .0825\, (I_t - 320)^2 \right] ,$$

where W_t is the number of men in the work force at the end of the t'th period of time, P_t is production in gallons per month, and I_t is the net inventory in gallons.

Optimal decision rules. Once the parameters of the cost function have been estimated, the decision rule may be obtained by first differentiating the cost function with respect to each decision variable (the P's and W's). The resulting system of linear equations may be solved rather readily for the decision rules. Fortunately, the results of this process may be reduced to a formula, requiring only a routine computation. It can be proved that the decisions made on the basis of the rule are optimal for the given cost function and forecast of future sales (see [19]).

On the basis of cost estimates that were made for the paint factory the necessary operations have been performed to obtain the optimal decision rules for production and the work force. The rule for production is:

$$P_1 = \sum_{t=1}^{N} w_t O_t + .993\, W_o - .464\, I_o + 153 ,$$

where P_1 is the production rate to be set for the next period, O_t is the forecast of orders from the warehouse t periods ahead, w_t are the weights to be attached to these forecasts (their numerical values, which depend upon the cost coefficients, are given in Table 1), W_o is the size of the work force at the end of the preceding period, and I_o is the level of inventories at that time.

Since the forecasts of future orders are averaged, production is smoothed in such a way that production "responds" optimally to changes in forecasted orders. The weight given to future orders declines rapidly as the forecast extends into the future. One implication of this is that there is not very much point in forecasting orders very far into the future. No information is required about the probability distribution of the errors of the sales forecast, except that the forecasts should be unbiased. This is a very important property of the rules, since such information is usually impossible to estimate.

The second term of the rule reflects the influence upon the scheduled production rate of the number of workers employed in the previous month. The more workers that are on the payroll at the beginning of the current month, the greater can be the rate of production without incurring overtime costs. Any large changes in the sizes of the work force would be costly.

The last two terms represent the inventory correction terms quite similar to those of the simple rule presented in the first part of this section. If the net inventory at the end of the previous month is large, then the negative term will exceed the other, and production will be decreased to lower the inventory level. Not only does this term determine how the optimal production rule responds to any given initial inventory situation, but it indicates how the rule will take account of past forecast errors, since their effect is to raise the net inventory above, or depress it below, the desired level.

The second decision rule is used to determine the size of the work force:

$$W_1 = \sum_{t=1}^{N} v_t O_t + .743 W_o - .010 I_o + 2.09,$$

where W_1 is the number of employees expected to be available at the end of the coming month, v_t are the weights attached to forecasts of future orders, and the remaining variables are the same as for the production rule.

Again, a term appears which is a weighted average of forecasts of future sales, but in this second rule the weights extend further into the future before they become of negligible size. The forecasts of distant sales are more important in setting the size of the labor force than that in production. If, for example, an increase in sales is expected to be a temporary one, then the adjustment should take place primarily in inventories and overtime production, rather than hiring more workers. But if the increase is expected to be permanent, it will even be worth-while to cut overtime production because there will be enough workers in a few months to produce the required products on regular time. The level of the labor force also depends upon the labor force at the end of the previous period and initial inventories, although the relative importance of these two terms is somewhat different for the two rules.

At this point we might review the general characteristics of the linear decision rules, to compare their properties with those of lot size formulas alone.

1. Although the derivation of the decision rules from the cost function is not trivial, the decision rules are very simple to use in setting production rates for each period of time. The decision rule need not be changed unless the relative costs of inventories, overtime, and turnover change.

2. Only a single-valued forecast of future sales is used; it is not necessary to have detailed knowledge about the distribution of forecast errors.

3. Inventories are adjusted in a way which is compatible with at least some of the production requirements -- the costs of inventories are balanced against the costs of overtime and changing the size of the labor force. It is possible to include other cost components if, for example, variations in work-in-process inventories are important (this was not the case at the paint factory).

The particular form of the cost function buys a great deal, but it should be remembered that some simplifying assumptions have been made in the development of these rules. We have, for example, not been able to include inequalities as constraints in the analysis, however, it is very unlikely that the solutions we have derived would violate the restrictions (for example, that total production must be positive).

IV. THE ITEM SCHEDULING PROBLEM

We have now indicated how the optimal aggregate production can be determined for the factory each month. The problem remains of allocating this aggregate production to individual items, and scheduling the items. This can propably be formulated as a static linear programming problem of reasonable size. We simply include P_1, the total production, as one of the constraints that the solution must satisfy. Hence, we have factored the original dynamic problem involving, say, 3,000 x^N variables into a quadratic programming problem involving N variables (only two of which have to be determined each month) and a linear programming problem to determine the item production schedule in one period.

In the actual application, we have not used linear programming methods to determine item production, but have resorted to a simpler technique. Again, this simplification appears to be justified in the particular situation, and its application to others will have to be examined in detail. Our basic assumption is the following: for any given total inventory, it is desirable that the inventories of individual items be roughly proportional to the expected orders for these items.

Let I_o be the aggregate net inventory on hand now, and P_1 be the aggregate production planned for the next month, as determined by the production decision rule. Let I_{oi} be the inventory of the i'th item on hand (or shortage, if it is negative) and let d_i be the fraction of expected total orders represented by this item (the d_i's should sum to unity). A production schedule that will satisfy our aggregate rule consists in producing the quantity P_{1i} of the i'th item in the next period, where:

$$P_{1i} = d_i (I_o + P_1) - I_{oi}.$$

Dividing the production P_{1i} by the lot size then gives the number of batches that are to be produced during the period (fractions are rounded to the nearest integral number).

Undoubtedly, a more satisfactory rule can be devised by using a more sophisticated procedure for determining the desired quantities of the individual items. However, the rule-of-thumb outlined here appears to operate satisfactorily in our specific case. Whenever the inventory at the end of the month is seriously out of balance, the rule concentrates production on items with low inventories.

For the case of two items, the proposed method is depicted graphically in Figure 8. The abscissa, x_1, refers to quantities of the first item; the ordinate, x_2, to quantities of the second. We plot the beginning inventory as a vector, $\vec{I}$, with components I_1 and I_2 ($I_1 + I_2 = I$, the aggregate inventory); and we draw the vector $k\vec{D}$ with components kd_1 and kd_2. From the results of the application of the linear decision rule, we draw the line $x_1 + x_2 = I + P$. Then $\vec{I} + \vec{P}$ is given by the intersection of this line with $k\vec{D}$, and $\vec{P}$ is given by the vector subtraction $\vec{P} = (\vec{I} + \vec{P}) - \vec{I}$. In the case illustrated, at the beginning of the month, the inventory of item 2 was too large relative to the inventory of item 1. Hence the rule schedules the production of a large amount of item 1 relative to item 2. The components of $\vec{P}$ must be non-negative; if this condition is not satisfied for all P_i at the intersection, we replace $\vec{P}$ by $\vec{P}'$, the vector "closest" to $\vec{P}$ that satisfies both the relation $\Sigma_i P_i' = P$ and the non-negativity requirements.

Operating tests of the decision rules

Having discussed the problems of determining optimal lot sizes, production rates, aggregate work force levels, and the allocation of total production among individual items, it is appropriate to ask to what extent, if any, these techniques have resulted in "better" manufacturing and distribution operations of the firm in question. Operating tests of the decision rules were carried out in three stages, which we will discuss briefly below.

1. Comparison with past performance: From the data of orders received and two kinds of forecasts (perfect prediction and moving-average of past sales, respectively), the resulting production rates, work force levels, and inventory levels were calculated, and the amount of run-outs and overtime work was estimated. In general, these rules would have resulted in somewhat more even production and fewer inventory run-outs. Some rather crude cost comparisons of these rules with actual performance indicates that rather substantial savings are possible with such scheduling policies. The costs of inventory, regular and overtime payroll, hiring and lay-offs, and inventory depletion were reduced by using the rules with a very crude forecast of future sales. A perfect forecast would have resulted in a relatively small amount of additional savings.

2. Scheduling a sample of the products: A sample of the paints, which represented about 25 percent of the sales volume, was then chosen to be scheduled with these techniques for further comparison with existing scheduling methods. Although it is difficult to compare the results here with what would have happened if the products were scheduled in the customary way, there is some evidence that production was leveled within rather narrow limits. At the same time both inventories and shortages were substantially lower than those experienced by the factory using normal methods.

3. Scheduling all products of the factory: Since August of last year, all of the products have been scheduled with the methods outlined in this report. Although the fluctuations in incoming orders since this time have been comparable with those previously experienced, production was leveled considerably with these techniques and inventories of finished goods were reduced. Of course, there are many problems of installation of these procedures, but the evidence so far is highly suggestive that the use of linear decision rules has important potentialities in production and employment scheduling.

REFERENCES

The references below indicate some of the main lines of development in the theory of production and inventory control. The list is not intended to be exhaustive and, since the references are only to published material, it is already somewhat out-of-date.

The "classical" lot-size formulas in inventory control are summarized in Alford and Bangs [1]; certain cases under uncertainty as well as some of the more recent developments are surveyed by Whitin [24, 23]. Simon and Holt [20] and Magee [16] have examined the relation of inventory control problems to those of production smoothing. Holt, Modigliani, and Simon [12] have further studied the interaction of production rate and inventory decisions with employment. A good introduction to the dynamic problem of inventory control may be found in Laderman, Littauer, and Weiss [15], with more technical expositions by Arrow, Harris, and Marschak [2]; Dvoretsky, Kiefer, and Wolfowitz [10]; Bellman, Glicksberg, and Gross [6]; and Beckman and Muth [3]. Some important technical reports on the production smoothing problem have been given by Bellman, Glicksberg, and Gross [5]; Modigliani and Hohn [17]; and Charnes, Cooper, and Mellon [7].

The applicability of servomechanism theory to production decisions was first examined by Simon [18]. Techniques for analysis of servomechanisms are well summarized by Truxal [21], who also reviews recent developments in the prediction problem studied by Wiener [25]. Such systems having certain optimal properties have been found by Holt and Simon [13] and Vassian [22]. A more complete exposition on linear decision rules, and their interpretation as servomechanisms, may be found in [12], the derivation from the cost function being presented in [11]. Simon [19] has demonstrated the optimal character of the rules under uncertainty. A somewhat different approach to dynamic programming problems (with functional equations) is reviewed by Bellman in [4] as well as the papers with Glicksberg and Gross already referred to. Techniques of linear programming are reported in Koopmans [14], and Charnes, Cooper and Henderson [7]. More recent developments, some of which have been applied to inventory and production rate problems, are reviewed by Dantzig [9].

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Table 1: Weights of Forecasts for the Production and Work Force Scheduling Rules

Period of time ahead t	Production Weights w_t	Work Force Weights v_t
1	.463	.0101
2	.234	.0088
3	.111	.0071
4	.046	.0054
5	.013	.0042
6	-.002	.0031
7	-.008	.0023
8	-.010	.0016
9	-.009	.0012
10	-.008	.0009
11	-.007	.0006
12	-.005	.0005

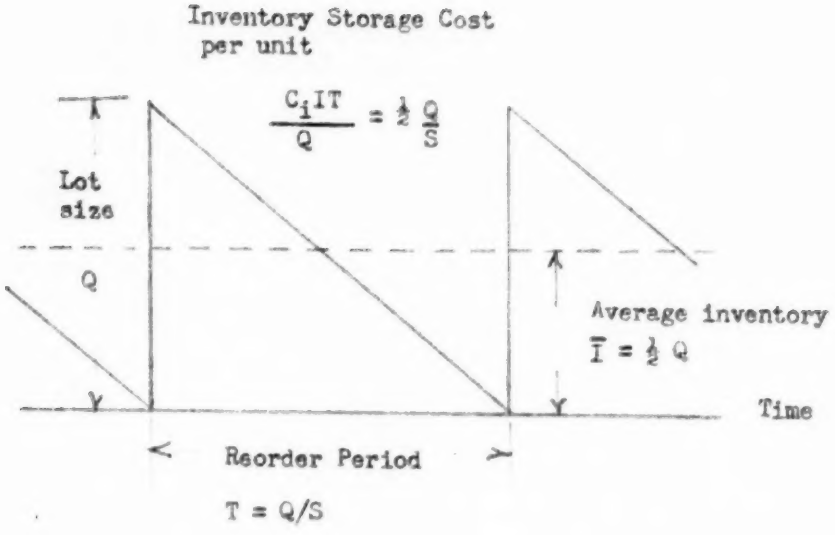

Fig. 1: Cost of Storage per Unit

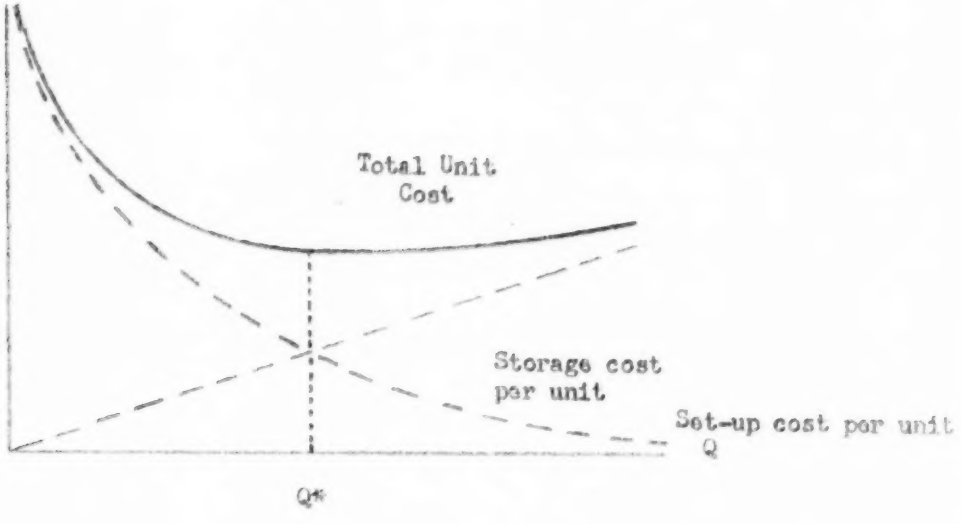

Fig. 2: Total Unit Cost as a Function of the Lot Size, Q.

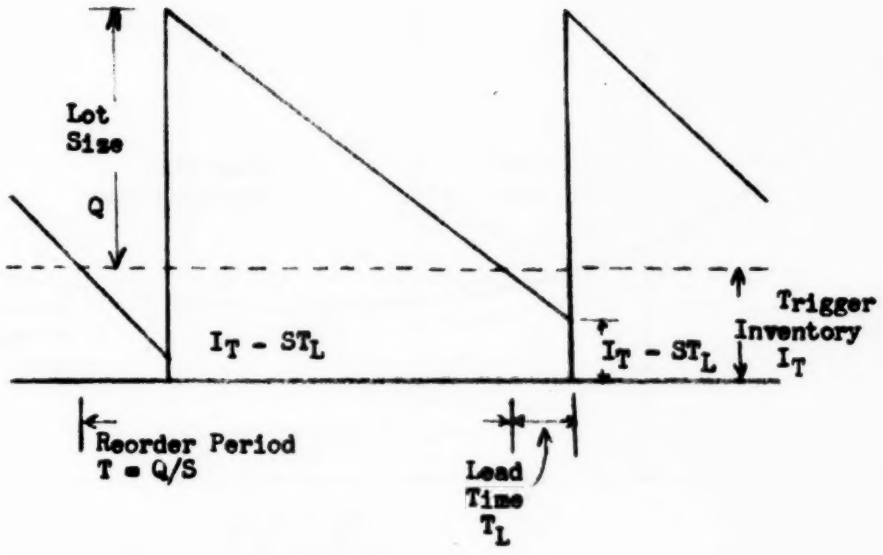

Fig. 3: Inventories with Buffer Stock

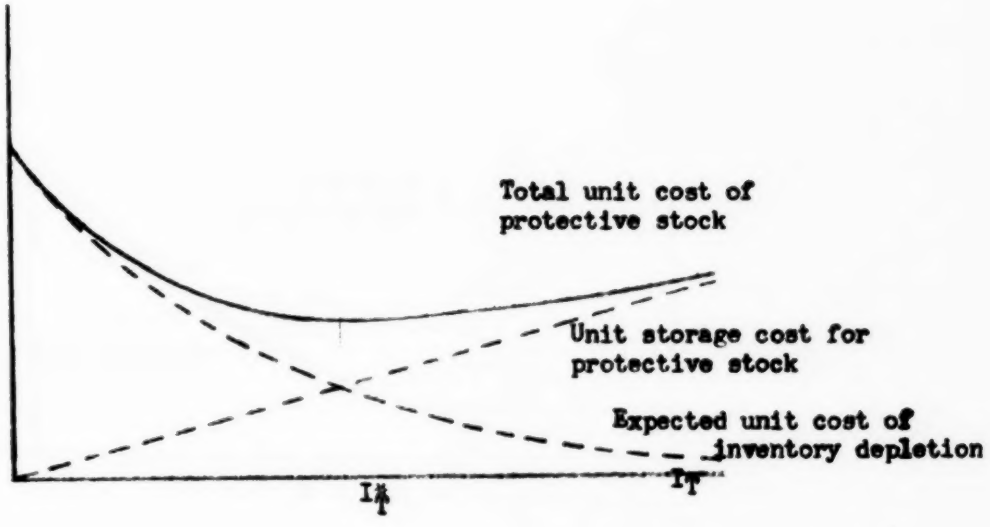

Fig. 4: Cost of Buffer Stock

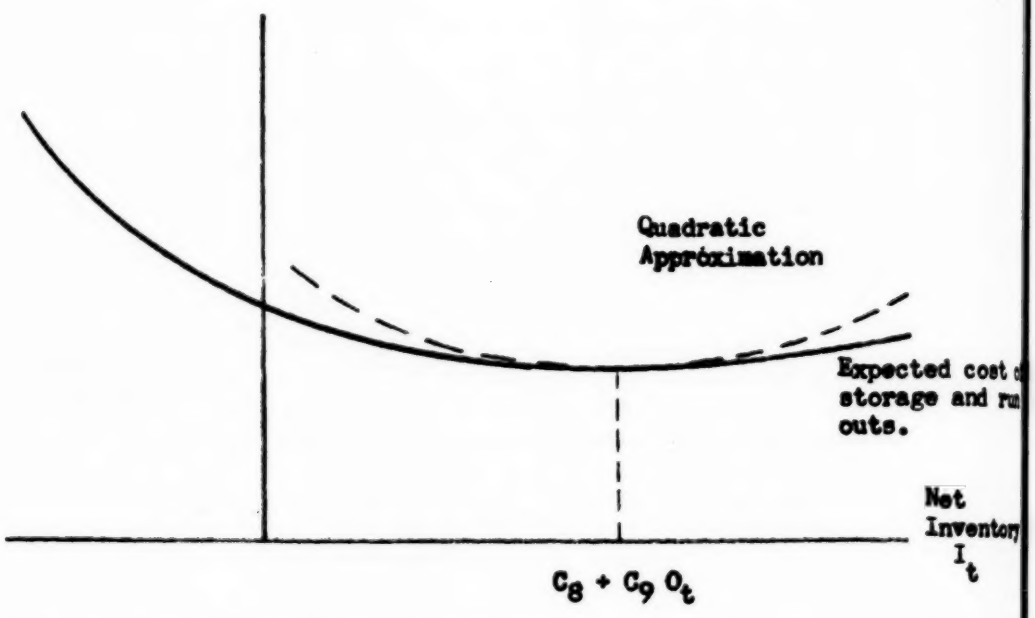

Figure 5: Cost of Inventory Storage and Depletion

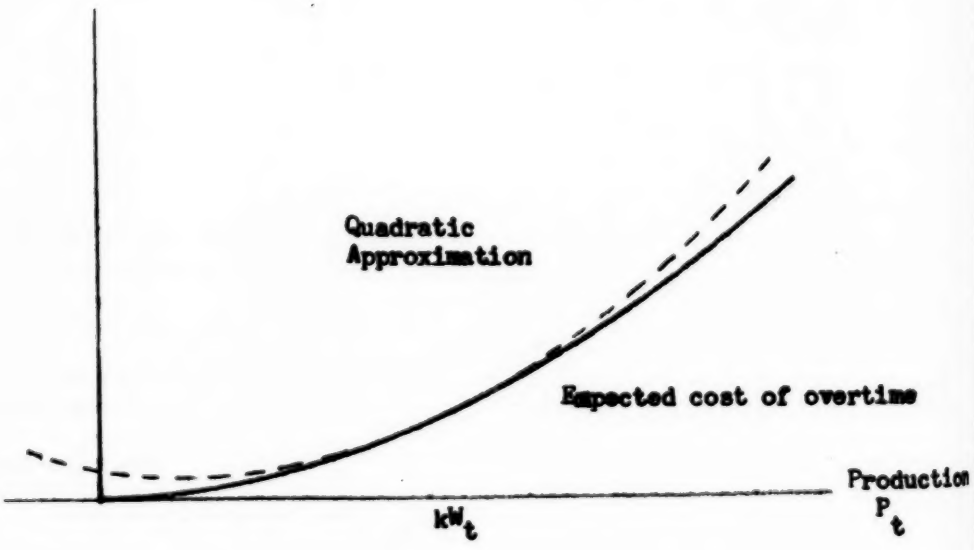

Figure 6: Cost of Overtime

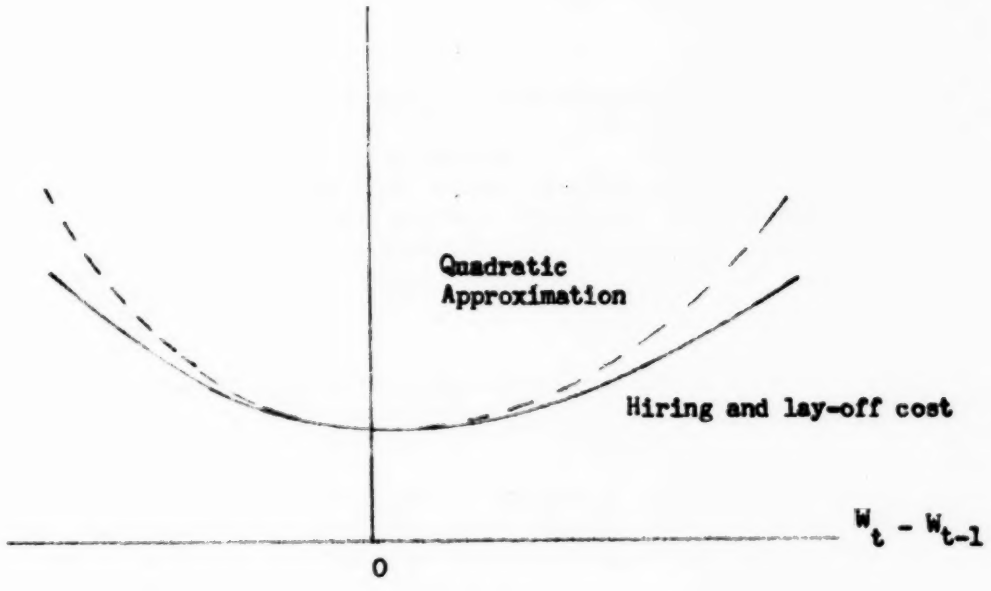

Figure 7: Cost of Labor Turnover

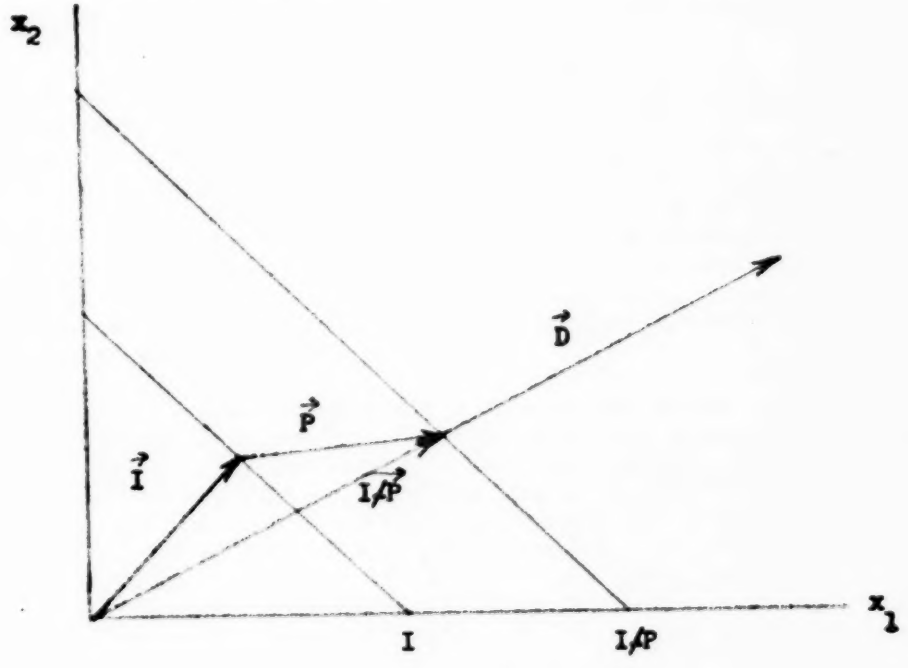

Figure 8: Calculation of Item Production

"TOOLING-UP" FOR SCIENTIFIC WORK MEASUREMENT

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INTRODUCTION

Engineering time standards of human work performance in the federal government presents a new challenge to industrial engineering. Two principal reasons for this are:

(1) Time-study in the federal government for years, - until 1950, - was prohibited by Public Law. Accordingly, there were at best very few personnel employed by the United States Government qualified and experienced in time-study.

(2) The removal of the prohibition against time-study in the federal government came at a time of a rapidly increasing and already acute shortage of engineers and time-study men.

The restriction against time-study operated through a rider to the Appropriations Act which when it became Public Law denied the use of public funds to pay the salary of any public servant engaged in taking a time-study through the use of any time-measurement instrument or device. However, this did not bar the application of work measurement in the federal government, so long as time-study per se was not utilized. Accordingly, we have had work measurement in the federal government in one form or another for many years. Generally, such work measurement was based on statistical standards historically derived, and in the Army has been known as the Army Performance Analysis System.

Historical standards provide a measure and in the absence of something better are good standards and certainly are better than nothing. However, historical standards have been telling us only what to expect on the basis of what has been accomplished in the past without indicating whether this past performance has been good or bad. With the advent of commercial-type accounting, industrial funds, and other demands upon us, it became necessary to have more realistic standards for more effective management, better planning, and more accurate mobilization planning. It, therefore, became incumbent upon us to find ways and means of implementing scientific work measurement techniques despite the virtual lack of trained personnel within the federal government and the scarcity of such personnel in the employment market.

This scarcity became more acute by virtue of the competition from industry, compounded by the superior compensation afforded by industry which attracted and retained most personnel qualified in these techniques. A rapidly mushrooming economy further contributed toward motivating qualified personnel toward industry rather than government because of greater opportunities, unrestricted by legislative salary ceilings, and because promotions generally were more rapid than was possible in government under the limitations of the Whitten Rider.

On the other hand, reference to the paucity of federal government employees trained and experienced in modern work measurement techniques is not intended to suggest or create the impression that scientific management has been unknown in the federal government. To the contrary, except in the area of time-study due to the legislative bar to time-study, great strides have been made in the pursuit and successful application of generally accepted progressive management techniques.

BACKGROUND

We in the Quartermaster Corps are singularly proud of our aggressive and comprehensive management engineering and industrial engineering programs which have been fully supported by top command and vigorously pursued continuously since their inception during World War II, in 1942. Although conceived and undertaken during the early war years, the Quartermaster Management Engineering Program continued without interruption at a high level through the post-war years, currently attaining its highest level of effectiveness. Yet despite the progress we have made we believe we are only at the threshold of our potential, and are dedicated to doing a professional job in the interests of management efficiency and optimum effectiveness in Government operations.

A portion of the Quartermaster Corps Management and Industrial Engineering Program for the fiscal year beginning 1 July 1956 has been made available to you (beginning on page 26A-1 of these proceedings) so that you may see for yourself its comprehensiveness and the relationship of my subject to the overall effort. My discussion on "Tooling-up" for Scientific Work Measurement deals only with one small segment of our program, that portion pertaining to engineered performance time-standards. It is this one small part of our over-all program I want to discuss and in so doing relate how we have met and are meeting the challenge confronting us and are preparing for concurrent implementation of engineered performance time-standards in 14 Quartermaster installations (13 Army depots and one Army post) situated from coast to coast in the continental United States.

It would be inappropriate to continue without giving credit and recognition to those who are responsible for our success to date, albeit we recognize that we barely have reached the threshold of that which we are striving to accomplish. Nevertheless, we would not be this far were it not for the vision and magnificent support of The Quartermaster General - Major General Kester L. Hastings, the QMC Comptroller - Colonel A. E. Dennis, the Chief of the Management Division - Colonel Manley C. Perry and his Assistant Chief - Clifford J. Brinkman.

First of all, the program to which I am referring is the Quartermaster Engineered Performance Time-Standards Program. It consists of QM System-wide formal training of personnel required to do the job, followed by implementation of the program through the installation of engineered performance time-standards, generally preceded by methods engineering, integration with the commercial-type accounting which we have in the QM System, and last but not least, continuing staff direction, supervision and follow-up.

We are using in our program stop-watch time-study, predetermined time-standards (Basic Motion Timestudy - BMT, except in the clothing factory of the Philadelphia QM Depot where Methods-Time-Measurement - MTM - is being used), standard data being developed by our personnel, work sampling, and statistical techniques.

PREPARATION FOR "TOOLING-UP" PHASE OF PROGRAM

I shall not retrace our steps back to the early days several years ago when we were conducting research in pre-determined times, when we were endeavoring to "sell" engineered performance time-standards, or through the period of many detours and frustrations. Suffice it to state that we were interested actively in engineered time-standards as early as 1950 and 1951, became seriously interested in exploring and researching predetermined times, beginning with MTM, in 1952, and were seriously and aggressively seeking to attain our objectives in this regard early in 1953.

Beginning more recently with the successful inception of the current effort (which is rapidly approaching realization and providing continuity through the first cycle of our training efforts), I recall the formation of a task group in August 1955 which included not only members from our Headquarters organization (Management and Installations Divisions) but also industrial engineering personnel from three of our field installations (Atlanta, Georgia; Jeffersonville, Indiana; and Ogden, Utah). This group helped prepare the original directive which announced the program (QMC Circular 178, dated 21 September 1955, Subject: QM Engineered Performance Standards Program). The task group also drafted a work measurement manual, a methods and standards handbook for the time-study personnel, and other useful material.

We proceeded on the assumption that our greatest guarantee of acceptance was understanding of the program and its impact upon supervisor and worker alike. We believed that the greatest assurance of proper understanding would be in the adequate orientation and familiarization of all personnel beginning with top command and working on down to the lowest paid worker echelons, dispelling insofar as humanly possible all along the way the myths, fables, fallacies, and misconceptions which our personnel had conjured over the years. This was based, further, on the belief that an informed clientele would provide a fully participating and cooperating force for successful implementation, whereas any other approach in such a venture would be doomed to failure. Moreover, we were aided materially in this endeavor and in all personnel aspects of the developing program by our fine Civilian Personnel Division headed by Civilian Personnel Director, John Will, and by Theodore Weinstein of the Civilian Personnel Division, one of the finest training officers any organization ever had the good fortune to have.

Accordingly, following the preliminary work of the task group and publication of the circular, we ventured on a flying orientation junket covering the six key depots in the early stages of the program. A team consisting of Mr. G. B. Bailey of the management consulting firm of J. D. Woods and Gordon, Ltd., Toronto, Canada, developers of Basic Motion Timestudy (BMT), Ted Weinstein - our Training Director, Herb Edlis - my assistant chief, and myself, visited the Quartermaster Depot at Richmond, Virginia, on a Wednesday last September, the general depot at Atlanta the next day - Thursday, the Quartermaster Depot at Jeffersonville, Indiana, Friday, the Sharpe General Depot at Stockton, California, the following Monday, the Utah General Depot at Ogden, Utah, Tuesday, and the Columbus General Depot, at Columbus, Ohio, Thursday. At each of the six depots we spoke to the commanding general or commanding officer of the depot and top officers and civilians of his staff each morning, and then to all supervisory personnel in the afternoon. Our audiences varied according to the size of the installation from relatively small numbers at the smaller depots to approximately 350 supervisors in the post theater at the Atlanta General Depot at the afternoon session.

At each session, with variations appropriate to the audience, - whether top management or supervisory personnel, - we presented a thorough orientation as to what the program was all about, why it was necessary and desirable, who was going to conduct it, when and where the classes would be and how the program would be implemented. We stressed at each depot that this is their program, we are merely the catalysts, and were there primarily to give assistance. We did not neglect to stress the impact on all concerned. We combined with our orientation mission a recruiting drive which drew many more applicants than were required. We held discussion periods and answered questions.

Generally we talked about two hours in the morning and approximately three hours in the afternoon. It was a grind, but it achieved its purpose and we enlisted support, generally unqualified and enthusiastic support from all the depot commanders. This was an auspicious beginning.

We recognized the need to give considerably more information and indoctrination to the top personnel who would be directly involved and responsible for the local implementation, --- and success of the program. Accordingly, as our first class of instructor trainees approached the end of its 33 weeks of training we brought the Comptrollers, Deputy Comptrollers, and Management Engineering Chiefs in to the Office of The Quartermaster General in Washington, D. C., in two groups, in April and May for two identical executive familiarization sessions. Most of each of these two sessions was conducted for us by Mr. G. B. Bailey of J. D. Woods and Gordon, Ltd., and we were able to go into considerably greater detail with these two groups over a period of three days for each than was possible in the exceedingly brief flying orientation visits of September. These executive familiarization sessions included stop-watch timestudy, BMT, work sampling, and work measurement systems.

This was particularly important because in the Quartermaster Corps the management and industrial engineering programs and activities are the principal function of the Management Engineering Division of each installation. The Management Engineering Division, in turn, is one of several organizational elements in the Comptroller's Office, and the Comptroller is directly responsible to the depot or installation commander. The implementation of the QM Engineered Performance Time-Standards Program at each installation is the assigned responsibility of the Methods and Standards Branch of the Management Engineering Division. Therefore, it is apparent how important it was to have a clear concept and understanding of the objectives and workings of the engineered standards program by the Comptrollers, Deputy Comptrollers, and the Chiefs of the Management Engineering Divisions.

Earlier in April 1956, comparable executive familiarization sessions, 20 hours and 40 hours respectively, for top executives of the Office of The Quartermaster General, military and civilian, were conducted by Mr. Don Stohlman of the management consulting firm of Serge A. Birn Companies of Louisville, Kentucky, and New York City, as part of the contractual requirements for management engineering services for the QM Clothing Factory at the Philadelphia Quartermaster Depot. Mr. Stohlman covered stop-watch timestudy, MTM, work sampling, incentive wage plans, and work measurement systems. The top management and executive personnel who attended these familiarization sessions also were invited to attend the subsequent BMT sessions. Many of our top OQMG personnel attended both sessions.

Unlike the QM System-wide approach, the clothing factory project was undertaken by contract. The contract included provisions for a Wage Plan Study, development and installation of a production control system, and installation of a work measurement system based primarily on training approximately 25 QM personnel of the clothing factory in stop-watch timestudy, MTM and work sampling. The QM clothing factory at the Philadelphia QM Depot is the only Army activity on a Piece Rate Incentive Wage Plan.

Getting back to our QM System-wide program, which is the basis for this presentation, the next step in this rather ambitious undertaking of orientation, familiarization, appreciation, and training, is the holding of a series of locally conducted appreciation sessions over an extended period of time for all supervisors, on a phased basis, so that familiarization of the supervisors concerned will keep pace with and precede actual engineering of standards in the work areas under the jurisdiction of the supervisors concerned. In this manner, we strive to dispel the mysteries of engineered time standards at the level of the first line supervisors and endeavor to get them "on the team".

That leads to the actual training program for the instructors and technicians who will spearhead the actual implementation of this program concurrently at 14 Quartermaster installations. In turn that brings us to the heart of my presentation, - "Tooling-up for Scientific Work Measurement in the Quartermaster Corps", as announced by our session chairman, Mr. Edlis.

What I am going to present now represents an approach, - our approach. It may not necessarily be the best approach and may well vary considerably from the practices of others in government and industry. Be that as it may, this approach, our approach, represents the culmination of considerable thought and study, and to our minds it is serving its purpose well. This approach represents the incorporation of the best thinking and practices we could find, adapted to our needs. We have built upon the experience of many others, without which we would have been lost. Perhaps others may profit from various portions of what we have done and are trying to accomplish.

THE "TOOLING-UP" PHASE

Our recruiting procedures (Chart 1) involve the official announcement of the program locally at each installation, followed by giving this announcement maximum publicity throughout each installation, and subsequently undertaking the careful screening of all applicants.

Each applicant is screened on the basis of his Standard Form 57 (Application for Employment) principally for education and experience.

Educational and experience criteria are such that 80 to 85 percent of all personnel at each installation are eligible to apply for enrollment in the program. Those who meet the minimum educational-experience criteria are then required to take a battery of tests which take from six to eight hours to administer. These carefully selected tests screen out a substantial number of the applicants. Those who pass are then subjected to a panel interview, the panel consisting of three to five key personnel at each installation. After this they are rated and ranked and a selection is made of the optimum candidates at each installation.

The entire process was administered locally at each of the six depots which contributed instructor trainees and will be repeated at each of the other seven depots and Fort Lee in selecting technician trainees for the program. On our System-wide swing our Headquarters Civilian Personnel Division, primarily through the personal contacts of Ted Weinstein, and subsequently by Don Magruder, also of Civilian Personnel Division, OQMG (in extending the orientation swing to installations subsequently providing technician trainees), furnished the guidance to local civilian personnel officials necessary so that each could administer the recruitment-selection process.

The Battery of Tests (Chart 2) includes tests for quantitative reasoning, vocabulary and reading comprehension, mechanical principles and pattern matching, a number series, comparison -perception, the Kuder Preference record - interest profile, the Allport-Vernon Study of Values, an administrative judgment test, the Guilford-Zimmerman test, and subsequently the panel interview. The Allport-Vernon and the Administrative Judgment Tests were given only to potential instructor and supervisory personnel, whereas the Guilford-Zimmerman Temperament Survey is administered only to potential technician trainees.

The Allport-Vernon study of values enabled us to assess the individual's theoretical, economic, aesthetic, social, political and religious values. The Guilford-Zimmerman Temperament Survey gave us some indication, --- although of course these tests serve only as a guide, --- of an individual's general activity or energy, restraint, seriousness, ascendance, sociability, emotional stability, objectivity, friendliness, agreeableness, thoughtfulness, personal relations, cooperativeness, masculinity of emotions and interests. We considered it important to the success of the program to screen all personnel for these attributes and qualities.

The panel interview which climaxes the selection process seeks to identify and evaluate those attributes and qualities not readily discernible by any written test, and to serve as corroboration or refutation of other aspects of the battery of tests. More specifically, the panel interview seeks to ascertain appearance, bearing and

manner, ability in oral expression, stability and social adjustment, mental qualities other than basic intelligence, interest and motivation, group leadership and participation, etc.

Interestingly enough, Mr. Weinstein has been able to run a correlation of results achieved to date with the results attained in the battery of tests described above, with a most significant outcome. Those who received the top scores in the battery of tests were at the top of their group in scholastic achievement in the training course. Conversely, those who ranked at the bottom of the battery of tests were at the bottom of their class in the actual training course. True, there wasn't a perfect correlation, particularly with respect to those who ranked somewhere in between the top and bottom in the battery of tests, some performing somewhat better in their class work than the battery of tests ranking would lead us to expect. However, generally we have been exceedingly well pleased with these tests as a guide for our purposes in the selection process.

Our trainees have come from a variety of sources (Chart 3), but with the exception of one individual at this reading in mid-May 1956 all have come within our own installations. Our objective in recruitment has been to recruit personnel, insofar as possible, from within, - personnel who have the know-how of our operations so that after they can acquire and become proficient in the techniques of timestudy they can become productive in a minimum of time, and more important be able to gain acceptance readily among their former fellow-personnel in operations, - the operations from which they came to enter this training program.

Of a total of 44 personnel trained as instructors or technicians to date, 14 have come from the staffs of our Management Engineering Divisions, 26 have come from the operating elements of our installations, and the remaining four are members of my Management Assistance Branch staff.

The actual source by job titles (Chart 4) is especially interesting in that it clearly indicates the diversified backgrounds of the trainees. The largest single source has been the organization and methods examiner or management analyst, from which we have derived 17, followed by 4 industrial engineers, 3 accounting and cost accounting personnel, 2 supply catalogers, 2 warehousemen, and one each of a variety of others: production process analyst, production control superintendent, statistical assistant, property and supply clerk, supply officer, executive secretary to the incentive awards committee, materials classifier foreman, mail clerk, tool stock and parts keeper, surplus property disposal officer, engineering draftsman, inspector of engineer items, spare parts requirements officer, supervisory freight traffic clerk, and a records management officer.

Surprisingly enough and quite gratifyingly, personnel who never have been exposed to industrial engineering or time-study techniques before have been doing reasonably well, and some have done almost as well and in some cases perhaps a little better than some of those who have had time-study experience or who are industrial engineers. As a matter of fact, we have had graduate industrial engineers who have been unable to pass the battery of tests described earlier. Of course, those industrial engineers who have been unable to qualify have not been admitted to the program.

The grades of our trainees (Chart 5) have ranged from wage board grades 6 through 11, wage board supervisory grades 3 and 4, and general service schedule personnel grades 4 through 13. The wage board employees are those commonly referred to as "blue-collar" workers, - those who are not subject to the Classification Act, as contrasted to the so-called "white collar" general service (GS) personnel.

Those among the general service schedule employees who were below grade 5 received an immediate promotion to grade GS-5 on entering the program. Likewise, the wage board workers below the equivalent GS-5 or GS-7 grades were promoted to the nearest of these GS grades. This means an extra added bonus for the GS-4 clerk qualifying for and entering the program, inasmuch as an immediate promotion to grade GS-5 is gained, and six months later upon satisfactory completion of the prescribed training course another promotion to GS-7 is earned. The equivalent situation developed with some of the lower graded wage board personnel.

The promotional opportunities indicated on Chart 5, whereby personnel in the lower grades particularly can qualify for a two grade promotion in six months, e.g., GS 5 to 7, and GS-7 to 9, without further reservations, upon satisfactory completion of the required training course were made possible through a QM System-wide training agreement entered into by our Civilian Personnel Division with the U. S. Civil Service Commission. This eliminates the necessity for each installation to bother about these details, and requires only that each installation consult the regulations and implement the System-wide agreement by contacting the local Civil Service Regional Office. We have had excellent collaboration and cooperation from the Civil Service Commission, without which our program could not have progressed as satisfactorily as it has.

The next chart (Chart 6) depicts the typical salaries of trainees prior to entering upon the program, subsequently upon entry into the program, six months later if they successfully complete the training course prescribed, and after a minimum of an additional year if they qualify for further promotion. This illustrates more

graphically than the previous grade structure chart what the promotional opportunities are and what they mean to the individual in actual annual salary. For example, the GS-4 clerk at $3415 per annum on qualifying for and entering into the program immediately was promoted to $3670 per year, and six months later upon satisfactorily completing the training course will be promoted to $4520 yearly, with additional opportunities available for promotion after a year's satisfactory performance on the job. Unfortunately, the opportunities, as the chart reflects, for the lower graded personnel are greater than for those in the higher grades. Accordingly, a GS-12 entering the program cannot hope for further promotion upon the satisfactory completion of the prescribed training program. This illustrates why the program attracts mostly personnel in the lower grades.

For those personnel in the lower grades who are attracted to this program, the U. S. Civil Service training agreement and promotional opportunities it provides generally offer ample incentive and motivation to remain with us and in the government at least for several years, inasmuch as faster promotional opportunities cannot be promised by any other government agency. This should result in a more favorable turn-over rate and through greater continuity assure us of a more effective program throughout the system. Of course, this is no safeguard from the enticements from industry, except that we hope such offers will not unduly deplete our human resources.

The Training Program (Chart 7) produces methods and standards technicians in 26 weeks and generated instructors after 33 weeks training on the first cycle. The training course comprises eight parts for instructors and six parts for technicians.

Part A for both instructors and technicians consists of training in methods improvement and an introduction to work measurement. This part covered a period of four weeks for the instructor-trainees but a more concentrated version is provided the technician trainees in two weeks. We are indebted to the Ordnance Management Engineering Training Program School at Rock Island Arsenal, formerly under the direction of Mr. Joseph Moquin and currently under Dr. Irwin Lazarus, for the fine methods improvement training and introduction to work measurement received by our trainees.

Part B consists of training in Stop-Watch Timestudy and Work Sampling. Our instructor trainees received this instruction during a period of two weeks from Mr. G. B. Bailey, while our technician trainees received and are receiving three weeks of training from our own recently trained instructors.

Basic Motion Timestudy (BMT) comprised Part C with Mr. Bailey providing three weeks of instruction in BMT to our instructor trainees, who subsequently provided and are providing four weeks of training in BMT to our technician trainees.

The formal class-room and laboratory work shop training in Parts A, B, and C are followed by a period of guided application training, Part D, under the full time guidance and supervision of a qualified instructor. The instructor trainees received seven weeks of guided application training from Mr. Harold Guilfoyle, an associate of Mr. Bailey's, while our technician trainees received and are receiving eight weeks of guided application training from our own instructors.

Having received 16 and 17 weeks fully supervised training the instructor trainees and technician trainees, respectively, then undergo an eight week period of application practice (Part E) pretty much on their own, with occasional spot supervision by the instructor. This is intended to put each individual on his own under actual working conditions to test his training, mettle and resourcefulness, and to season each into a self-confident time-study man.

In the case of the instructors there followed a two week course in methods of instruction (Part F) given by Mr. Weinstein and two associates for the purpose of insuring that the potential instructors having assimilated the technical training in the techniques of time-study would in turn be able to communicate their learning effectively to their students in turn.

As further insurance, the instructor trainees then conducted six weeks of supervised teaching (Part G), covering Parts B and C with 27 trainees of the first technician trainee class, Class No. 2. This was fully supervised teaching, with the instructor-trainees being supervised and guided not only by experienced time-study personnel, but also by the Civilian Personnel training officers, who constantly sought to improve the teaching techniques of the instructor-trainees.

Part H for the instructor-trainees and Part F for the technician trainees covered approximately one week for final examinations and a critique, then graduation.

In conducting Part G, the supervised teaching portion of the training course, the 16 instructor-trainees were divided into five instruction teams and the 27 technician trainees were divided into five student groups. Each of these groups was placed in a separate class-room, all reasonably adjacent to each other, permitting our experts to circulate freely among the five concurrent classes in order to assist, guide, generally supervise, and evaluate progress by both instructor-trainees and technician trainees. In addition each technician-trainee had an opportunity to evaluate each of his instructors.

Out of the 33 weeks training program we have developed ten senior instructors, six instructors, and one assistant instructor. From the 26 weeks training program we are developing methods and standards analysts and assistant methods and standards analysts, - the techni-

cians of the program (Chart 8). We require that a senior instructor be in charge of a course of instruction, assisted by one or more instructors or assistant instructors. The determination of the final title conferred on a graduating trainee is based upon individual attainment and proficiency gained through a variety of evaluations: written tests, examinations, observation and the personal evaluation by the instructor, projects in class, actual work projects during the guided application training period, and other factors.

The 33 weeks training period for the first group of instructors was based on a "crash program" calculated to generate a cadre of qualified instructors in our "tooling-up" period, who in turn could train the required number of methods and standards analysts needed to engineer performance time-standards concurrently throughout the QM System at 14 installations, of which 13 are industrial depots. Having laid a firm foundation through the expediency of the above noted "crash program", we can afford to be more deliberate about qualifying instructors henceforth. Accordingly, in the future, it will require a minimum of 58 weeks and two days for an individual to qualify as an instructor. All the technician-trainees now in training and those scheduled to begin training this summer in Classes 3, 4, 5 and 6, as well as those who will follow these first six classes, will have an opportunity to qualify as instructors after meeting the prescribed requirements.

Chart 9 indicates that the first requisite to qualify for an instructor in the future will be successful completion of the 26 weeks basic training course and qualification as a methods and standards technician. This will have to be followed by another 26 full weeks of actual on-site full time experience in practical application of engineered performance time-standards. Those who then wish to be considered for certification as instructors will have to pass special qualifying examinations, including panel interviews. Thereafter, there will be two weeks training in methods of instruction, followed by four weeks advanced technical training. It is likely that to this period there will be added seven weeks of supervised practice teaching before the instructor's certificate is made final, which, if it materializes will extend the training required to qualify as an instructor to a total of more than 65 weeks. These then should become adequate instructors worthy of perpetuating the program we have begun.

The concept of the QMEPTS Program we are currently implementing is graphically illustrated in a "nut-shell" in the "explosion" chart (Chart 10). The nucleus indicated the original 19 trainees from six depots and OQMG who began instructor training in October 1955. Two fell by the way-side, leaving 17 to continue, -- all of whom graduated after 33 weeks of training. They in turn are training 27 technician-trainees from six depots and Fort Lee as part of their supervised teaching requirements. Thereafter, these 27 technician trainees will

be divided into two groups, with one going to the Richmond QM Depot and the other to the Schenectady General Depot for Part D, Guided Application Training. The instructors from Richmond QM Depot will supervise the guided application training at Richmond, while one of the OQMG instructors, assisted by the instructor from the Sharpe General Depot, will supervise the guided application training at Schenectady. At the same time, or shortly thereafter, four concurrent classes will be formed, at Atlanta, Columbus, Utah and Jeffersonville.

Out of these classes we are generating trained personnel capable of implementing the QMEPTS Program concurrently at all 14 participating installations. Including the 25 personnel trained at the Philadelphia QM Depot clothing factory we shall have produced 114 trained personnel within 14 months. Actual implementation of the program with the engineering of time-standards is scheduled to begin late in September 1956 at Richmond QM Depot, and all 14 QM installations will have begun engineering standards in earnest, no longer in a training status, before 1 January 1957.

In engineering performance time-standards, and more especially in developing standard data, our trained personnel will first endeavor to apply BMT where-ever possible, or in the alternative use one of these other techniques, in the order of priority listed: stop-watch timestudy, work sampling, statistical, and engineering estimates. (Chart 11). Of course, as standard data is developed, our trainees will use time formulas and standard data as much as possible.

In an effort to accelerate the development of standard data and promote the interchange of ideas, methods, and standards we are planning to establish a QM Methods and Standards Central Office at the Columbus General Depot which will serve as a central clearing house for standard data. Chart 12, which I refer to as my "implosion" chart, shows that we plan to have at least three depots working concurrently in an assigned area developing standard data, which will flow from each of the depots to the Central Office. There it will be investigated and validated, and if validated it will be included within a Standard Data Manual which will be disseminated in loose-leaf form, at least initially, among all depots. Of course, standards will not be set at our level, at the central office, or at any one installation for all installations. Standards actually will be developed locally on-site, although where-ever applicable the local methods and standards personnel will make ample use of available standard data.

It is our opinion that we can facilitate the validation of standard data being generated at the installation level for inclusion in the QM System Standard Data Manual by having at least three depots working in the same functional areas and operations. Through that device we hope that at least two of the three depots, and preferably

all three, will come reasonably close, within certain predetermined tolerances, plus or minus, in developing standard data. This being so, the task of the central office in accepting and inserting such standard data in the standard data manual is simplified. However, should there be wide disagreement on the part of one depot as against two in reasonbly close agreement, the one depot in disagreement can be investigated more quickly with relation to the particular standard data in question, and should all three depots be in significant disagreement that may well be a clue that all three should reexamine what they have done.

Our target for first cycle coverage at all 13 QM and General Depots (Chart 13) is 31 December 1959, or approximately three years from the completion of training of our first six training classes. We anticipate that progress will be rather slow at first, but that our trained personnel will gain momentum as their increasing experience sharpens their technical proficiency.

CONCLUSION

The greatest danger to our progress is identical to the reasons which were the basis for this rather ambitious training program, - the lack of trained time-study personnel, - such lack resulting from premature losses to industry and other government agencies. However, we hope that the extensive and concentrated training (which our Civilian Personnel people estimate is worth the equivalent of $10,000 per trainee, counting salary, travel, per diem, cost of instruction, etc.), the promotional opportunities which outline a career pattern for the young and ambitious, the challenge presented by the job to be done, and the agreement which we require from each trainee that he shall remain with the government for at least a year after successful completion of his training, will all contribute to retention of a maximum number of the personnel we are training and plan to train. We are optimistic about retaining the majority of the trainees for at least three years, which should see us through the first cycle coverage. In the meanwhile we plan a program for continuing regeneration of technicians so that the program can be self-perpetuating within reason and so that we shall not be left without trained personnel at any one time.

It will be most deplorable if it develops that we have succeeded only in spawning embryos which will mature in the employ of others, for this tooling-up process is not only time-consuming but expensive, and we must produce results commensurate with the expenditures of time and money to justify our investment.

In recapitulation (Chart 14), I have indicated that our trainees are recruited from within our own internal sources insuring us know-how in at least some of the potential areas for engineering standards and

thereby facilitating extension of the program through greater acceptance. I also outlined the extensive battery of tests each applicant must take and pass assuring better quality of trainee personnel, which through reduction of failures means more for our training dollar. I outlined our training program of 33 weeks for the first group of instructors (58 to 65 weeks for future instructors) and 26 weeks of technicians, and delineated each of the component parts. Further, I covered our anticipation of generating 114 trained personnel in little over a year after starting from "scratch", and how we have planned for an adequate supply of instructors and technicians through a self-perpetuating program. Finally, I explained our plan to develop standard data quickly and exchange it among all depots in order to help attain our goal of one complete cycle coverage in three years.

As I stated near the beginning of this presentation, this may not be the best approach, nor may it be the answer for our own problems. We are convinced that this was the best answer for us under the circumstances, and are confident that we are giving the tax-payer more through this approach for less than by any other means we could employ in implementing an engineered performance time-standards work measurement program. Far more, we have met the challenge, and seek to continue meeting the challenge that faces us until tangible worthwhile results are evident. We hope this will reflect creditably on the industrial engineering profession, as well as on the public servants who pursue this program and on the Quartermaster Corps we serve.

I thank you.

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TOOLING UP FOR SCIENTIFIC WORK MEASUREMENT in the Army Quartermaster System

● PRESENTED BY JOHN A. REVROS, CHIEF, MANAGEMENT ASSISTANCE BRANCH, MGMT DIV, OFF QMC COMPT, OQMG

CHART 1

RECRUITING PROCEDURE

Once Program is announced and publicised-applicants are screened on following basis . . . .

- EVALUATION OF EDUCATION & EXPERIENCE
- BATTERY OF TESTS (6to8 hrs)
- PANEL INTERVIEW
- RATED & RANKED
- SELECTION OF OPTIMUM CANDIDATES

CHART 2

BATTERY of TESTS

7 hrs 45 min for Instructors & Supervisory Personnel
6 hrs 15 min for Technician Trainees

1	CSC *56B QUANTITATIVE REASONING	4 HRS 15 MIN
2	CSC * 9 B VOCABULARY & READING COMPREHENSION	
3	CSC * 12 MECHANICAL PRINCIPLES & PATTERN MATCHING	
4	CSC * 14 NUMBER SERIES	
5	CSC * 41 COMPARISON - PERCEPTION	
6	KUDER PREFERENCE RECORD-INTEREST PROFILE	1 HR
7	* ALLPORT-VERNON - STUDY OF VALUES	30 MIN
8	* CSC *450 ADMINISTRATIVE JUDGMENT TEST	2 HRS
9	** GUILFORD-ZIMMERMAN TEST	1 HR
10	* PANEL INTERVIEW	

* Instructors & Supervisory Personnel *ONLY*
** Technician Trainees *ONLY*

CHART 3

A SOURCE of TRAINEES*

to DATE - MAY 56

14 Management Engineering Divisions

26 Installation Operating Elements

4 OQMG Management Division

44 INSTRUCTOR & TECHNICIAN TRAINEES

* Does not include PQMD Clothing Factory

CHART 4

B SOURCE of TRAINEES by JOB DERIVATION

17 ORGANIZATION & METHODS EXAMINERS

4 INDUSTRIAL ENGINEERS

3 ACCOUNTING & COST ACCOUNTING PERSONNEL

2 SUPPLY CATALOGERS

2 WAREHOUSEMEN

and one each of:

Production Process Analyst	Exec. Secretary, Incent. Awards Prog.	Engineering Draftsman
Production Control Superintendent	Materials Classifier Foreman	Inspector of Engineer Items
Statistical Asst	Mail Clerk	Spare Parts Requirements Officer
Property & Supply Clerk	Tool Stock & Parts Keeper	Supervisor Freight Traffic Clerk
Supply Officer	Surplus Property Disposal Officer	Records Management Officer

CHART 5

GRADES of TRAINEES

BEFORE PROGRAM	ENTRY INTO PROGRAM	6 MONTHS LATER *	AFTER ADDITIONAL YEAR
WB - 6	✓GS - 5	✓✓GS - 7	✓✓✓GS - 9 **
WB - 7	✓GS - 5	✓✓GS - 7	✓✓✓GS - 9 **
WB - 11	✓GS - 7	✓✓GS - 9	✓✓✓GS - 11 **
WBS - 3	✓GS - 5	✓✓GS - 7	✓✓✓GS - 9 **
WBS - 4	✓GS - 7	✓✓GS - 9	✓✓✓GS - 11 **
GS - 4	✓GS - 5	✓✓GS - 7	✓✓✓GS - 9 **
GS - 6	GS - 6	✓GS - 7 or 8	✓✓GS - 9 or 10 **
GS - 7	GS - 7	✓GS - 9	✓✓GS - 11 **
GS - 8	GS - 8	✓GS - 9 or 10	✓✓GS - 11 **
GS - 9	GS - 9	✓GS - 11	✓✓GS - 12 **
GS - 10	GS - 10	✓GS - 11	✓✓GS - 12 **
GS - 11	GS - 11	✓GS - 12	✓✓GS - 13 ?
GS - 12	GS - 12	GS - 12	✓GS - 13 ?
GS - 13	GS - 13	GS - 13	GS - 13

* IF QUALIFY

** FURTHER PROMOTIONAL OPPORTUNITIES WITHIN QM SYSTEM POSSIBLE

- PROMOTION = ✓
- FURTHER PROMOTION = ✓✓
- ✓✓✓

CHART 6

TYPICAL SALARIES of TRAINEES

PRIOR	ENTRY INTO PROGRAM	6 MOS LATER	AFTER ADDITIONAL YR
$3415 (GS-4)	$3670 (GS-5)	$4520 (GS-7)	$5440 (GS-9)
$4525 (GS-7)	$4525	$5440 (GS-9)	$6390 (GS-11)
$5440 (GS-9)	$5440	$6390 (GS-11)	$7570 (GS-12)
$6390 (GS-11)	$6390	$7570 (GS-12)	$8990 (GS-13) ?
$7570 (GS-12)	$7570	$7570	$8990 (GS-13) ?

CHART 7

QM SYSTEM-WIDE *EPTS* TRAINING PROGRAM

PART		COURSE	WEEKS	
INSTRUCTORS	TECHNICIANS		INSTRUCTORS	TECHNICIANS
A	A	Methods Improvement & Introduction to Work Measurement	4	2
B	B	Stop Watch Timestudy & Work Sampling	2	3
C	C	Basic Motion Timestudy (BMT)	3	4
D	D	Guided Application Training	7	8
E	E	Application Practice (*on own*)	8	8
F	-	Methods of Instruction	2	0
G	-	Supervised Teaching	6	0
H	F	Final Evaluation & Critique	1	1
			33	26

CHART 8

PROGRAM DEVELOPING

- SENIOR INSTRUCTOR
- INSTRUCTOR
- ASSISTANT INSTRUCTOR
- METHODS & STANDARDS ANALYST
- ASSISTANT METHODS & STANDARDS ANALYST

CHART 9

REQUIREMENTS *for* FUTURE INSTRUCTORS

	WEEKS
Successful completion Basic Training Course and certification as qualified Methods & Standards Technician	26
Actual on site full time experience	26
Pass qualfying exams to pursue Instructor Training (includes Panel Interviews)	2 DAYS
Training in Methods of Instruction	2
Advanced Technical Training	4
	58+

CHART 10

FROM 0 to 114 TRAINED PERSONNEL in 14 MONTHS

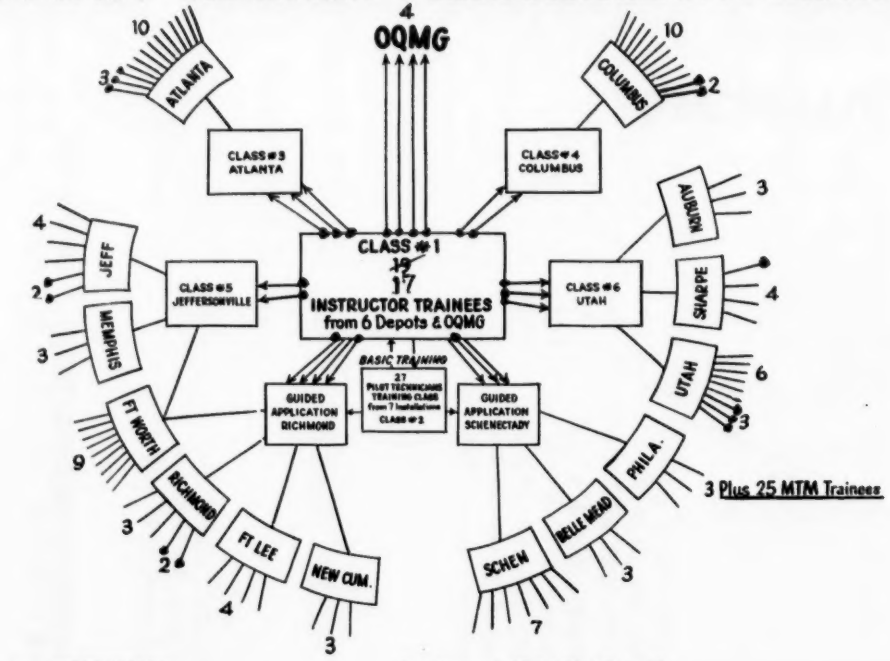

CHART 11

PRIORITY OF APPLICATION of APPROPRIATE TECHNIQUES

BMT WHERE-EVER POSSIBLE

STOP-WATCH TIMESTUDY

WORK SAMPLING

STATISTICAL

ENGINEERING ESTIMATES

CHART 12

DEVELOPMENT of STANDARD DATA

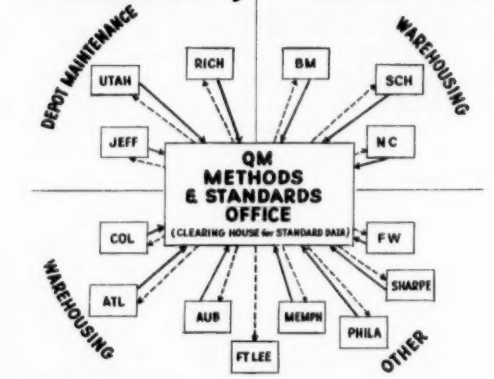

CHART 13

TARGETS FOR FIRST CYCLE COVERAGE
At all 13 QM & General Depots

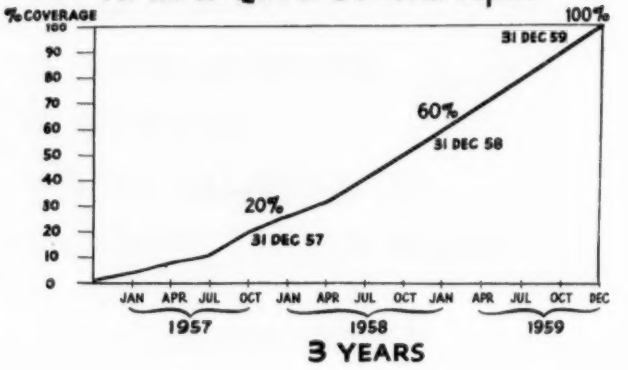

CHART 14

RECAPITULATION

- SOURCE OF TRAINEES
- BATTERY OF TESTS
- TRAINING PROGRAM
- PROGRAM DEVELOPING INSTRUCTORS & TECHNICIANS
- FROM 0 TO 114 TRAINED
- BUILDING STANDARD DATA
- FIRST CYCLE — 3 YRS

ANNEX TO TALK ON
"TOOLING-UP" FOR SCIENTIFIC WORK MEASUREMENT

John A. Nevros

QMC PROGRAM NO. 4 - COMMAND AND MANAGEMENT - FY 1957
PART VI - MANAGEMENT
CHAPTER II
MANAGEMENT ENGINEERING ACTIVITY

SECTION I - OBJECTIVES

1. General. The objectives of QM Management Engineering shall be to achieve at minimum cost and consistent with the QMC mission the optimization of operational effectiveness and efficiency and the minimization of costs throughout the QM System. This is to be accomplished by each echelon of the Quartermaster System continuously developing and implementing its own schedules of management improvement actions and all personnel being made improvement conscious, sustaining such improvement consciousness, and participating in the improvement effort.

2. Specific.

a. WITHIN THE OFFICE OF THE QUARTERMASTER GENERAL.

(1) Management Assistance

(a) Management Engineering Activity Program. Management Division, OQMG, prepare the FY 1958 Management Engineering Activity segment of QMC Program No. 4 - Command and Management, Part VI - Management.

(b) Management Improvement Plan. Management Division, OQMG, promulgate a Management Improvement Plan for FY 1958 for the Quartermaster System.

(c) Industrial Engineering - Engineered Performance Time-Standards. Management Division complete the industrial engineering training courses for sixty (60) methods and standards technicians from all QM System depots and Fort Lee in five classes and provide technical direction, staff supervision, technical guidance and assistance to all QM and General depots and to Hq., QM Training Command, so that the methods and standards personnel trained from these installations can begin engineering methods and standards at their installations by 1 January 1957. The QM Target is for 10% coverage of the program by 31 December 1959, contrasted with the DCSLOG target for completion by 31 December 1958. Management Division, OQMG, also to complete advanced training of approximately fifteen (15) Quartermaster instructor personnel (graduates of Group I, Class No. 1) during FY 1957 in the application of predetermined time-standards (BMT) work measurement techniques to clerical operations.

(d) Management and Industrial Engineering Research, Development and Applications. Management Division discover, develop if necessary, and apply within the QM System the latest and most suitable management and management engineering systems, techniques, tools, equipment, machinery and devices. Undertake at least one such new project during FY 1957 and include at least four visits to industry, colleges or universities, or professional management society or association conferences or meetings (approximately one each quarter) for the purpose of keeping current with and adapting for QM System purposes where applicable the latest significant advances in scientific management.

(e) Work Simplification. Management Division complete training courses covering approximately 50% of OQMG supervisors. Each supervisor in OQMG who has satisfactorily completed training in work simplification submit at least one installable work simplification proposal during FY 1957. Each supervisor in OQMG, by the end of FY 57, to have a current Supervisor's Management Manual.

(f) Planned Management Improvement Projects. Each supervisor in OQMG to identify at least two areas or problems within his jurisdiction for significant improvement during FY 57 and to report progress on each planned improvement quarterly until completed and implemented.

(g) Coordination and Staff Supervision of all Management and Industrial Engineering Personnel and Activities. Management Division, OQMG, in exercising its responsibility for coordination and staff supervision of all management engineering personnel and activities during FY 1957 establish a QM Work Measurement Panel to comprise representatives of all OQMG organizational elements of primary interest for the purpose of providing policy guidance to and reviewing the progress of implementation of the QM Engineered Performance Time-Standards Program; and shall also establish a QM Management Improvement Council of management engineering personnel which shall meet quarterly to coordinate management improvement efforts and activities, exchange ideas, and motivate increased participation in the program.

(h) Exchange of Ideas. Management Division, OQMG, to disseminate throughout the QM System one OCA management information packet each month and supplement these packets by at least one QM management information packet each quarter. In addition, circulate among QM installations at least one of the best adopted management improvements each quarter developed by a QM installation.

(i) Management and Industrial Engineering Self-Improvement. In furtherance of this objective, Management Division, OQMG, during FY 1957, revise the QM Management Career Incentive Program so that it can be utilized to train and develop new management and industrial engineering personnel as needed for the QM System.

(j) Management and Industrial Engineering Field Evaluations. Management Division, OQMG, systematically review and evaluate the effectiveness of the Management Improvement Plan while in operation, evaluate the effectiveness of installation management and industrial engineering activities and accomplishments to identify areas of possible improvement, and provide maximum management assistance by conducting management engineering field evaluations at at least eight (8) QM installations during the Fiscal Year. Through concentrated added management assistance substantially increase the management and industrial engineering effectiveness of at least two selected QM installations to be evidenced by an improvement in the adjective evaluation of two installations during FY 1957 over that attained in FY 1956.

(k) Reporting Management Improvements. Management Division, OQMG, on the basis of improvements generated throughout the QM System to submit one management improvement report each quarter through DCSLOG to the Comptroller of the Army, and in addition to prepare and submit to The Quartermaster General and higher authority an annual management improvement report for FY 1956. Each organizational element in OQMG (Offices & Divisions) quarterly to submit to Management Division outstanding improvements, manpower activities, and work simplification activities. Management Division also to submit a bi-weekly report of outstanding accomplishments to the Assistant Secretary of the Army (Logistics).

(l) Management and Industrial Engineering Services Contract at Philadelphia QM Depot. Through staff direction, technical supervision, and management assistance, to assist the Philadelphia QM Depot in bringing Contract DA 44-109-QM-2012 with the Serge A. Birn Companies for management engineering services for the Manufacturing Division to a successful completion during FY 1957 and help the depot begin second cycle coverage of industrially engineered methods and standards on its own.

(m) Office Machine Systems. Conduct at least one industrial engineering study during FY 57 on new office machine systems of potential value to the QM System.

(n) OQMG Management Engineering Field Representatives. Management Division, OQMG, to bring in its field representatives at least semi-annually for consultation, re-orientation, and training.

(2) Management Systems.

(a) Management Systems Research. Management Division, OQMG, to constitute at least one Management Systems Research Team of three to five personnel, augmented as necessary and desirable by participants from other OQMG elements and QM installations.

(b) Operations Research Techniques. Apply the techniques of Operations Research to QM System Operations in at least three (3) instances (Projects).

(3) Management Surveys. Management Division, OQMG, to complete six (6) QM System-wide Management Improvement Cyclic Management Engineering Surveys during FY 1957.

(4) Organization.

(a) OQMG Organization Manual. Management Division, OQMG, to accomplish one complete review of QMC Manual 19-10 during FY 1957 and revise manual as necessary, authorizing publication of a maximum of eight changes to the manual during the fiscal year. Each Chief of an office or division in OQMG to review his portion of QMC Manual 19-10 at least once during FY 1957 to assure the accuracy and currency of the statements therein and advise Management Division of any discrepancies, and recommend additions or deletions as necessary.

(b) Single Managership. Management Division, OQMG, complete the organizational implementation of single managership assignments.

(c) Quartermaster Commands. Management Division, OQMG, undertake and complete during FY 1957 a review of the organization of QM Commands, seeking improvement in the organizational structure thereof.

(d) QMC Manual 19-13. Management Division, OQMG, to accomplish one complete review of QMC Manual 19-13 during FY 1957 and revise the manual as necessary. Management Division to perform a continuing review of additions, deletions, and changes to QMC Manual 19-13. Each supervisor in OQMG to review those portions of QMC Manual 19-13 in which he has a primary interest at least once during FY 1957 and recommend such additions, deletions or changes thereto as may be necessary.

(e) QM Missions. Management Division, OQMG, during FY 1957 to complete development of QM media for mission assignments.

(f) Services to Non-QM Activities. Management Division, OQMG, during FY 1957 to complete indexing of services provided by QM installations to non-Quartermaster activities.

(g) Mobilization Plans. Management Division, OQMG, during FY 1957, undertake and complete a study of mobilization plans.

b. THE QUARTERMASTER INSTALLATIONS MANAGEMENT ENGINEERING 11 POINT PLAN FOR FISCAL YEAR 1957 (QM MEP) for Quartermaster Installations and Activities of the QM System. The general objectives stated in par. 1 above shall be implemented through a dynamic and realistic Management Engineering Plan, hereinafter referred to as the MEP, by each Quartermaster installation (and activity separately located), based in part upon the specific objectives below.

(1) Management Engineering Surveys

(a) Point 1 of the MEP: Systematic Cyclic Management Reappraisal Surveys (MRS's). Complete comprehensive surveys need be made only of the Storage and Depot Maintenance Divisions. Problem identification surveys shall suffice for all other organizational elements during FY 1957 (Also see par. 3b - Policies).

(b) Point 2 of the MEP: Industrial Engineering - Engineered Performance Time-Standards (EPTS). All depots and Fort Lee shall provide personnel to be trained in industrially engineered methods and time-standards work measurement techniques in accordance with QMC Circular 178, 21 September 1955. Technicians training classes shall be conducted by the Atlanta General Depot for Atlanta technician trainees (Class No. 3), by the Columbus General Depot for Columbus technician trainees (Class No. 4), by the Jeffersonville QM Depot for technician trainees from the Jeffersonville, Fort Worth and Memphis Depots, and by the Utah General Depot for technician trainees from the Auburn, Sharpe and Utah Depots. Richmond QM Depot shall conduct guided application training for technician trainees from Belle Mead, New Cumberland, Philadelphia, Schenectady, Richmond Depots and Fort Lee. All Depots and Fort Lee shall begin engineering methods and standards on a productive basis at their installations by 1 January 1957. The QM target sets a minimum of 10% coverage of operations at each of these installations during FY 57 with the QM target for completion of complete coverage (first cycle) established for 31 December 1959, although there is a likelihood that the target for 100% completion of the program (first cycle) may be advanced to 31 December 1958, in conformance with DCSLOG requirements. Each depot and Fort Lee, during Fiscal Year 1957 shall:

1. Identify the areas and operations susceptible to coverage by EPTS.

2. Establish priorities for progressive application of EPTS.

3. Maintain "before and after" records upon which evaluation of the QM EPTS Program savings and benefits can be based.

4. Seek maximum methods improvement and process improvement in installing engineered standards, consistent with the schedules adopted for installing standards and standard control systems.

5. Specifically incorporate an Industrial Engineering EPTS segment in the FY 57, FY 58, and FY 59 Management Improvement Plan for the installation.

6. Attach EPTS schedules and progress against such schedules as Part IV of each Quarterly Management Improvement Report to OQMG.

7. Undertake EPTS implementation in coordination with all operating and staff personnel and organizations which are concerned or affected, in order to utilize all experience and skills available and to obtain proper balance, cooperation, understanding, and acceptance.

8. Establish an EPTS Committee which shall represent such interests and experience indicated in subpara 7 above for obtaining proper coordination and acceptance at the installation.

(c) Each QM installation other than a depot or Fort Lee, shall identify those areas and operations which are feasible of and susceptible to establishment of engineered standards, and shall establish priorities for progressive application of industrially engineered standards and submit a list of these areas, operations, and priorities to Management Division, OQMG, for review and concurrence. Subsequently, methods and standards technicians shall be trained at selected QM training sites beginning prior to the end of FY 1957. An EPTS Committee shall be established subsequent to the training of methods and standards technicians for the installation.

(d) Point 3 of the MEP: Special Management Engineering Projects. Study or survey selected organizational elements, major functions and processes, inadequate or substandard performance or utilization of resources, and administrative control requirements including reports control, records management, and forms control. Seek through special projects, solution of problems identified during cyclic management reappraisal studies which were not resolved during latter

studies. At depots, further implement the Depot Command Management System. At all depots conduct projects for the installation Program Coordinator and Program Advisory Committee. Prepare and/or maintain mobilization and domestic emergency plans. Conduct such other special projects as are required or desirable.

(e) Point 4 of the MEP: Management Systems Research. Identify problems desirable and economically feasible and susceptible to, solution by the application of Operations Research techniques (particularly applicable to those installations which were represented in the QM Operations Research techniques (particularly applicable to those installations which were represented in the QM Operations Research Class #1 and similar subsequent classes). After first definitely having ascertained the feasibility, desirability, and economic preferability, utilize and apply discriminatingly and selectively operations research techniques and tools to the best possible advantage when such tools are superior to other scientific management techniques and tools previously available and are likely to provide a better solution, and a greater return for a smaller investment of time, funds and other considerations.

(2) "Self-Help" Programs (Staff Direction and Technical Supervision of)

(a) Point 5 of the MEP: Work Simplification Program (WSP). Train all supervisors who have not satisfactorily completed the 12 hour Department of the Army work simplification course since 1951. Require each supervisor who has satisfactorily completed a 12 hour training course since 1951 to submit at least one installable work simplification proposal during FY 1957. Require each supervisor to maintain a current Supervisor's Management Manual.

(b) Point 6 of the MEP: Planned Management Improvement Projects. Require each supervisor at every organizational level to identify one area or problem within his jurisdiction for significant improvement during each quarter of FY 1957 and to report progress on each planned improvement quarterly until completed and implemented.

(c) Point 7 of the MEP: Coordination and Staff Supervision of All Management Engineering Personnel and Activities. Establish a Management Improvement Council of management engineering and management engineering type personnel to meet quarterly to coordinate management improvement efforts and activities, exchange ideas, and motivate increased participation in the Management Improvement activities of the installation.

(3) - Management Assistance

(a) Point 8 of the MEP: Standardization and Documentation of Policies and Procedures. Accomplish a complete review of a random sampling of installation policies, and procedures. In addition, each organizational element of the installation to review those policies and procedures of primary interest and concern to the organization at least once during FY 57 and recommend such additions, deletions, or changes as may be necessary to bring the pertinent policies and procedures up to date.

(b) Point 9 of the MEP: Management and Industrial Engineering Self-Improvement. Develop and conduct an internal management and industrial engineering training program for such personnel as are not assigned to the QM EPTS Program (MEP Point 2) for at least thirteen consecutive weeks during the last half of Fiscal Year 1957.

(4) Other

(a) Point 10 of the MEP: Planning, Programming, Scheduling and Reporting.

1. Develop and promulgate early during the 4th Quarter the annual Installation Management Improvement Plan (MIP) which shall include a Management Engineering Plan as a segment thereof, which MEP shall have an overall tentative master schedule of activities, based upon the MEP for the entire fiscal year, of which only the first month shall be firm and the others tentative.

2. Develop and promulgate during the 2nd quarter a Management Engineering Plan for the calendar year to be substituted for the Management Engineering Segment of the FY Installation MIP. In effect this constitutes a revision of the management engineering segment, bringing it up to date for the subsequent 12 months, and in effect providing a recurring semi-annual revision.

3. Prepare and publish monthly schedules of management engineering projects each covering a two months period.

4. Prepare and submit to OQMG a quarterly management improvement report (RCS CSCAM-10(R2)).

(b) Point 11 of the MEP: Miscellaneous. Include in the MEP the following: Exchange of Ideas, Organization Control, Manpower Utilization and Control, Forms and Reports Control, Statistical and Program Review and Analysis, and Graphics Services and Consultation.

SECTION II - POLICIES

3. General. Management engineering activities within the Quartermaster System shall be conducted with least interference to operations, in recognition of and conformance with command prerogatives, and consistent with requirements by higher authority. All major problems having significant improvement potential shall be resolved or referred to appropriate action elements for timely resolution, and agreement shall be reached expeditiously, within available resources so that savings and benefits may be realized promptly. Solution to minor problems may be deferred in the interests of maintaining schedule accomplishment, achieving timeliness in solution and implementation of major problems, and gaining time for other potentially more productive projects. QM management and industrial engineering personnel shall be alert at all times to adapt or apply the latest proven management techniques and tools to QM System operations.

a. WITHIN THE OFFICE OF THE QUARTERMASTER GENERAL.

(1) Management Assistance.

(a) Management Engineering Activity Program. Preparation shall begin early in the 3rd Quarter. Each branch chief in the Management Division and the Executive Secretary of the QM Incentive Awards Committee shall submit their individual segments by the end of January.

(b) Management Improvement Plan. A Management Improvement Plan for the Quartermaster System shall be prepared in accordance with par. 11, AR 1-60.

(c) Industrial Engineering - Engineered Performance Time-Standards

1. Target for Completion. The QM target for completion of the first cycle coverage of the program at QM System depots by 31 December 1959 was established in QMC Circular 178 dated 21 September 1955 based on the total number of personnel authorized to implement the program. The total number of personnel authorized is based on an empirical ratio of one methods and standards personnel required for every 200 personnel in mission operations (storage, depot maintenance and stock control) or a ratio of one-half of one percent per 100 mission personnel. The original ratio determined necessary to begin such a program and complete one cycle coverage within two years (by December 1958) was one technician per 100 personnel or a ratio of one percent per 100 employees in operations susceptible to the engineering of methods and standards. When the total estimated requirement of personnel to implement the program was reduced by 50% the initial effort was limited to mission activities at depots and the target extended to December 1959. If the DCSLOG target of 31 December 1958, which is one year earlier than the QM target and includes all operations susceptible to engineering

of standards at all installations, is to be met additional classes will have to be authorized by OQMG and additional methods and standards technicians trained during Fiscal Year 1957. The targets for progress in implementation and completion of the first cycle coverage based on current QM policy contrasted with suggested targets to meet the DCSLOG target are indicated below:

	FY 57			FY 58				FY 59				FY 60	
Quarter	2	3	4	1	2	3	4	1	2	3	4	1	2
QM Policy	1%	5%	10%	15%	20%	30%	40%	50%	60%	70%	80%	90%	100%
DCSLOG Target	5%	10%	20%	35%	50%	65%	80%	90%	100%	-	-	-	-

2. The first half of FY 57 shall be devoted to completion of the "tooling-up" process for the program, completing training of the personnel (five classes) authorized in QMC Circular 178 of 1955, and beginning the systematic industrial engineering of methods and standards in storage and depot maintenance operations at depots (support activities at Fort Lee).

(d) Management and Industrial Engineering Research, Development and Applications. Management Division shall engage in continuing management, management engineering and industrial engineering, research, development and applications with participation and assistance from QM installations as required, consistent with the manpower resources available.

(e) Work Simplification. Management Division shall train, guide and assist (through continuing follow-up) all supervisors in OQMG in the making of systematic improvements in their operations through the use of work simplification techniques and the maintenance of a current Supervisor's Management Manual by each supervisor (except that only one manual is required where there is a military chief and civilian assistant chief); and also give continuing impetus to the program in order to sustain interest and maintain a high level of productivity. Resulting outstanding improvements to be referred to the Incentive Awards Committee for consideration. WSP training to be given only by qualified management engineering personnel having an ability to train personnel in classes not to exceed 15 trainees, and preferably 10 or fewer, over a minimum of 12 hours instruction and laboratory sessions. Submission of an installable proposal is a requisite for satisfactory completion of training. For the purpose of the WSP, a supervisor is defined as the head of each organizational element authorized in the organization manual (QMC Manual 19-10). Management Division, OQMG, also shall continue its staff direction and technical supervision of the work simplification program at QM installations and give impetus to sustaining the program in the field at a high level of interest and productivity.

(f) Planned Improvement Projects. Management Division, OQMG, shall encourage each supervisor at every organizational level to identify projects within his jurisdiction for significant improvement in order to generate specific action in removing management deficiencies, and to report on accomplishment or progress toward accomplishment of each planned improvement at the end of each Management Improvement Reporting period, with outstanding improvements to be referred for consideration by the Incentive Awards Committee. Also, each supervisor at every organizational level shall be encouraged to determine quarterly the elements or operations of his organization where the greatest relative emphasis for improvement effort should be placed; and to identify outstanding improvements (not limited to accomplishments of planned improvement projects or to accomplishments by supervisors only) for encouragement, recognition, as an incentive to further improvements, and as a measure of the results of the improvement effort in each organizational element.

(g) Coordination and Staff Supervision of all Management and Industrial Engineering Personnel and Activities. Management Division, OQMG, shall coordinate the activities of all management and industrial engineering and management engineering type personnel throughout the QM System and provide staff supervision to such personnel in order to avoid unnecessary duplication in management and industrial engineering efforts and to integrate such efforts into the most effective homogeneous force for optimum management improvement.

(h) Exchange of Ideas. Management Division, OQMG, shall provide recurring management assistance through the broadest dissemination of management information and the maximum exchange of ideas and improvements (QM, Army, Defense Establishment-wide). Each supervisor at every echelon throughout the QM System is responsible for referring to Management Division significant information for possible dissemination, and outstanding improvements and ideas for possible exchange or circulation among other organizational elements and among installations and activities in the field.

(i) Management and Industrial Engineering Self-Improvement. Management Division, OQMG, shall maintain and steadily increase the proficiency of QM management and industrial engineering personnel through training programs and management development programs.

(j) Management and Industrial Engineering Field Evaluations. Management Division, OQMG, shall strive to provide maximum assistance on an annual basis (more or less) through systematic management and industrial engineering on-site evaluations in order to enhance continually the effective-

ness of management engineering staffs throughout the QM System and thereby increase the value and gains potential of the management and industrial engineering personnel at each installation.

(k) Reporting Management Improvements. The management improvement report is the medium by which each organizational element (OQMG Offices and Divisions, and QM installations and activities) informs The Quartermaster General of its improvement efforts. Evaluation of progress and the extent of management improvement in each organizational element will be based on the outstanding improvements, manpower activities, and work simplification proposals reported. The information submitted by organizational elements will also be used as a central source of information for portraying the QM System's efforts to improve its operations, as well as source material for reporting outstanding accomplishments bi-weekly to the Assistant Secretary of the Army (Logistics).

(l) Management and Industrial Engineering Services Contract at Philadelphia QM Depot. Maximum return from investment in contract to be derived at the earliest opportunity.

(m) Office Machine Systems. Management Division, OQMG, shall strive to keep current on latest developments in this field and conduct industrial engineering studies of those systems and equipment of greatest potential value to the QM System.

(n) OQMG Management Engineering Field Representatives shall be well rounded generalists in all aspects of management and industrial engineering in order to provide optimum liaison with the installations and activities in assigned geographic area.

(o) Continuing Program Objectives. Other objectives which are exceedingly difficult if not impossible to schedule and generally equally as difficult or impossible to measure but which have a significant impact upon the provision of management and industrial engineering services are:

1. Management Consulting Services. Management Division, OQMG, shall provide management consulting services throughout the QM System. This includes management engineering and industrial engineering consulting services.

2. Special Projects Requested by TQMG and Other Officials. These cannot be anticipated but frequently are time-consuming.

3. Participation on Task Groups, Committees, etc. Participation on the QM Automatic Data Processing Systems Task Group, the U. S. Civil Service Board of Examiners for Industrial Engineers, and various OQMG Committees.

4. Cost Consciousness Program monitorship.

5. Staff Direction of QM System Management and Industrial Engineering Staffs and Personnel. Provision of management assistance on request or as required.

6. Management Engineering Public Relations for QM System. Management Division, OQMG, provides management consulting service, guidance, advice, and information upon request to other technical services of the Department of the Army, and also upon request to the Departments of the Navy and Air Force, and other non-Defense federal government agencies. Also presents status, progress, concept, and accomplishments of the QM Management Improvement Program and the QM management engineering efforts to professional societies and associations and others.

(2) Management Systems.

(a) Management Systems Research. Management Division, OQMG, shall identify problems desirable and economically feasible of, and susceptible to solution by the application of Operations Research techniques. Management Division, OQMG, shall constitute Management Systems Research Teams where the magnitude of the problem warrants such approach, augmented as necessary and desirable by participants from other OQMG elements and QM installations. Management Division, OQMG, shall also apply discriminatingly and selectively the operations research techniques and tools to the best possible advantage when such techniques and/or tools are superior to other scientific management techniques and tools previously available and are likely to generate a better solution and a greater return for a smaller investment of time, funds, and other considerations. Management Division, OQMG, also shall consider the feasibility and desirability of constituting Management Systems Research task groups comprising OQMG and interested installation personnel, and augmented as necessary by WAE (When-Actually-Employed) experts or consulting personnel, or recommending contractual arrangements when evaluated best from all aspects and considerations. Management Division, on its own initiative, shall also recommend, where appropriate, either referral of major problems to the Army Operations Research Office or utilization of contractual arrangements where the interests of the QMC will be served best by the latter approach. Management Division, OQMG, shall provide progressively increasing guidance, assistance, staff and technican direction and supervision over management systems research activities throughout the QM System.

(b) Electronic Automatic Data Processing Systems. Management Division, OQMG, to continue active participation in management systems research and analysis seeking potential QM applications of electronic automatic data processing systems. To whatever extent possible, integrate the ADPS effort within the overall structure of management systems research, as one or two teams of the total management systems research group.

(3) Management Surveys. OQMG System-wide Management Improvement Surveys shall be scheduled on a cyclic basis covering primarily functional areas which in OQMG may cross organizational lines and are concerned with both departmental and field activity. Some surveys in this program are directed at specific organizational elements in OQMG. Surveys serve to analyze program objectives and to evaluate the appropriateness, effectiveness, and economy of policies, procedures, and organization, for attainment of program targets.

(4) Organization.

(a) Organization Control. Management Division, OQMG, shall exercise system-wide control of organizational structures to provide maximum standardization and concomitant effectiveness, efficiency, and economy of operations.

(b) Special Management and Industrial Engineering Surveys and Projects. Management Division, OQMG, shall make studies or management and industrial engineering surveys of selected organizational elements of the Office of The Quartermaster General, of major functions and processes, and of inadequate or substandard performance or utilization of resources. These studies shall include organizational studies, overall functional management engineering surveys, and special management engineering projects as directed, requested, or required, and shall determine through periodic non-cyclic appraisals the need for refinement, revision or improvement of policies, mission, organization, procedures, and functions for greater effectiveness, efficiency, and economy.

(c) Standardization and Documentation of Policies, Systems, Procedures, and Work Methods. Management Division, OQMG, shall provide continuing management assistance throughout the QM System on the standardization and documentation of policies, systems and procedures, and shall establish and maintain adequate controls over such standardization and documentation.

(d) Management Consulting Services. Management Division, OQMG, shall provide management consulting services throughout the QM System on organization, missions, procedures, organization manuals and procedures manuals.

b. FOR QUARTERMASTER INSTALLATIONS AND ACTIVITIES (QM 11 POINT MEP)

(1) Management Engineering Surveys

(a) MEP Point 1: Cyclic MRS's. Each installation shall survey each of its organizational elements (or functional areas) annually on the basis of a 3-Cycle varied approach (one complete comprehensive MRS every three years) except that during Fiscal Year 1957 complete comprehensive surveys need be made only in Storage and Depot Maintenance Divisions, problem identification surveys sufficing for all other organizational elements. This authorizes a suspension of complete comprehensive management reappraisal surveys of all organizational elements except Storage and Depot Maintenance for this fiscal year only, thereby extending the normal 3-Cycle varied approach to a 4-Cycle period (FY 57 through FY 60) insofar as complete comprehensive management reappraisal surveys are concerned in order to release available management engineering mandays to better adjust to current and anticipated accelerated demands. Further, management reappraisal surveys of any type are not required of organizational elements with fewer than eleven (11) personnel spaces, and shall not be made of organizational elements having fewer than six (6) personnel spaces.

(b) MEP Point 2: Industrial Engineering - Engineered Performance Time-Standards. (Also see par. 3a(1)(c) above). A Methods and Standards Branch shall be established in the Management Engineering Division at each depot and Fort Lee which branch shall have the sole and exclusive responsibility to industrially engineer methods and standards. The methods and standards branch personnel shall establish all engineered performance time-standards at all installations except in the Philadelphia QM Depot's Manufacturing Division and in the Ordnance Depot Maintenance Shop at the Atlanta General Depot. No personnel shall be eligible or authorized either to engineer time-standards or to instruct other personnel in engineered time-standards work measurement techniques unless such personnel have satisfactorily completed the prescribed QM course and training period as evidenced by the award of an appropriate certificate as an instructor or practitioner. Neither shall the Methods and Standards Branch at any QM installation be headed by anyone except personnel duly trained and certified by OQMG as authorized personnel. The head of the Methods and Standards Branch shall report directly to the Chief and/or Assistant Chief of the Management Engineering Division. Methods and Standards personnel shall not be assigned any other duties nor participate in management reappraisal studies or other management engineering division projects. They may serve as consultants on these other projects on a limited minimum time consuming basis. The personnel requirements for the QM EPTS Program set forth in Annex C of QMC Circular No. 178 dated 21 September 1955 are minimum require-

ments but the total additional required column on Annex C represent the maximum additional personnel spaces to be made available during FY 1958 by OQMG. However, if the installation commander can make additional personnel spaces available from within his existing resources he may if he sees fit augment the staff of the Methods and Standards Branch in order to accelerate implementation of the program so long as all additional personnel are trained by OQMG licensed instructors for a minimum of 26 weeks and so long as such augmentation does not derive from personnel reductions previously committed to OQMG.

(c) MEP Point 2 Continued. Priorities.

1. All depots except Fort Worth, Jeffersonville, Richmond, and Utah shall engineer time-standards in depot operations in the following order of priority: QM Storage Division first; - at general depots followed by all other Storage activities, - and then by all Depot Maintenance activities in order.

2. Jeffersonville, Richmond and Utah shall engineer time-standards first in QM Depot Maintenance Operations. Utah will then concentrate on all other depot maintenance operations, and then on storage operations. Jeffersonville and Richmond will proceed from depot maintenance to storage.

3. Fort Worth shall start in the Signal Supply Section.

4. Fort Lee may set its own priorities.

5. In order to avoid duplication and accelerate implementation, close control and integration of areas of coverage at and by each installation shall be maintained at all times by OQMG (Management Division).

(d) MEP Point 2 Continued. Revised Integrated Approach for Attaining Maximum Benefits from Engineered Performance Time-Standards and Accelerating Implementation of the Program. Target for all installations beginning productive installation of engineered time-standards is generally January 1957. Accordingly,

1. Beginning immediately each installation solicit and encourage personnel within the top-priority activity indicated in par. c above to submit a maximum number of employee suggestions and work simplification proposals during the 1st Quarter, FY 57. This to be followed in the 2nd Quarter, FY 57, by a complete comprehensive management reappraisal study of the top priority element. Time-Standards would be engineered in the top priority element as soon as

trained personnel are available, regardless of some overlapping in point of time with the management reappraisal study. Installation of time-standards would be followed by a special management engineering sruvey for the purpose of following up on the implementation of recommendations of all preceding phases. This approach to be repeated within one activity after another on the basis of the priority accorded each activity for the engineering of time-standards.

2. Maximum attention to be devoted by the methods and standards technicians to development of standard data and the interchange of standard data among QM installations.

3. Priority of utilization of industrial engineering techniques in each instance, depending on feasibility, time, and cost, to be standard data, BMT (MTM in PQMD Clothing Factory), stop-watch study, work sampling, engineered statistical standards, engineering estimates, and staffing patterns.

(e) MEP Point 3: Special Management Engineering Projects. Management Consulting shall be considered special projects. This includes, at a general depot, the services furnished by the depot storage consultant. In planning and developing the installation MEP be liberal in allocating estimated man-days requirements for special projects, using special projects to provide a measure of flexibility in the program. Of all the elements of an installation program it is MEP Point 3 - Special Projects that will be most susceptible to widely fluctuating demands, most difficult to plan, and control.

(f) MEP Point 4: Management Systems Research. (Also see par. 3a(2) above.) QM installations and activities when in doubt as to the suitability, desirability, or applicability of appropriate operations research techniques and tools shall refer such doubtful potential applications to Management Division, OQMG, for guidance and assistance. QM installations and activities also shall refer to Management Division, OQMG, problems identified as susceptible to a profitable operations research team approach.

(2) "Self-Help" Programs

(a) MEP Point 5: Work Simplification Program. Policies stated in par. 3a(1)(e) above are applicable here too. Schedule, for retraining, beginning 4th Quarter, FY 57, supervisors previously trained but who have not submitted an installable work simplification proposal during the three years prior to 31 December 1956. Publicize this and exempt from retraining requirement those supervisors who submit an installable proposal during 3rd Quarter, FY 57, following prior publicity of plan to retrain supervisors.

(b) MEP Point 6: Planned Management Improvement Projects. Policies stated in par. 3a(1)(f) above are also applicable here. The same definition of a supervisor used for USP applies here also.

(c) MEP Point 7: Coordination and Staff Supervision. The Management Engineering Division shall coordinate the activities of all management engineering and management engineering type personnel within the installation.

(3) Management Assistance

(a) MEP Point 8: Standardization and Documentation of Policies and Procedures. The Management Engineering Division shall provide continuing management assistance on the standardization and documentation of policies and procedures, and shall maintain adequate controls over such standardization and documentation.

(b) MEP Point 9: Management and Industrial Engineering Self-Improvement. Management and industrial engineering personnel are to be encouraged to join and participate in activities of professional societies and associations.

(4) Other

(a) MEP Point 10: Planning, Programming, Scheduling & Reporting. Each annual MIP to include a long range plan covering a period of time equivalent to and coinciding with four (4) planned cycles of management reappraisal surveys coverage (4 years) for FY 1957 only.

(b) MEP Point 11: Miscellaneous.

(c) MEP Point 12: Optional Elements. During regular management and industrial engineering field evaluation visits credit in the form of bonus points is awarded an installation for implementation of the optional elements of the program. No penalty is assessed if the optional points have not been implemented.

4. References. The following references prescribe rules and regulations affecting the execution of this program.

AR 1-60
AR 10-82
SR 11-110-1, 780-5-1, 10-10-1, 10-10-2
DA Program Document No. 2
DA Pamphlets, 20-345, 20-300, 20-301
PL 429 - 80th Congress
BOB Bulletin A-8
Executive Order No. 10072
DA Pamphlet No. 35-10, The Comptroller's Guide.

OFFICE OF THE QUARTERMASTER GENERAL (1)	PROGRAM TITLE: OMC COMMAND & MANAGEMENT PROGRAM (2)	PROGRAM NO.: 4 - PART VI - MANAGEMENT (3)
ACTIVITY: MANAGEMENT ENGINEERING ACTIVITY (4)	SUB-ACTIVITY: MANAGEMENT ASSISTANCE (5)	
☐ COMMAND PROGRAM SCHEDULE ☒ OPERATING PROGRAM SCHEDULE (6)	PROGRAM SCHEDULE FOR OQMG (7)	ORIGINAL ☐ CHANGE NO. (8)
		DATE: 26 March 1956 (9)

BREAKDOWN OF ACTIVITY/SUB-ACTIVITY (Objectives and Workload) (10)	UNIT (11)	FISCAL PROJECT (12)	PHASED OBJECTIVES OR WORKLOAD FISCAL YEAR 1957 (13)				
			1ST QTR	2D QTR	3D QTR	4TH QTR	TOTAL
1. QM Management Engineering Activity Program for FY 58	Project	2012	0	0	1	0	1
2. QM Management Improvement Plan for FY 58	Project		0	0	1	0	1
3. QM Engineered Performance Time Standards							
a. Technicians Training Classes	Class		1	4	0	0	5
b. Technicians to be trained	Trainee		22	38	0	0	60
c. Installation of Stds at Depots and Fort Lee (QM Target for 100% completion is 31 December 1959)	Average Total Installation Coverage		0	1%	5%	10%	10%
d. One Week Advanced Trg. for QM Instructors in BMT Clerical Work Measurement Applications	Class		0	0	0	1	1
4. Management Engineering Research							
a. Mgmt. Engineering Research	Project		0	0	0	1	1
b. Visits to Industry or Prof Conf's	Visits		1	1	1	1	4
5. Work Simplification Program							
a. 12 Hrs. Trg. of OQMG Supervisors	Coverage		35%	40%	45%	50%	50%
b. Ea. Trained OQMG Supervisor Submit at Least One Installable Proposal	Project		25%	50%	75%	100%	100%

OFFICE OF THE QUARTERMASTER GENERAL (1) | PROG ACTIVITY: QMG COMMAND & MANAGEMENT DETAIL | PROGRAM: 4 - [illegible] (3)

ACTIVITY: MANAGEMENT ENGINEERING ACTIVITY (Continued) (4) | SUB-ACTIVITY: MANAGEMENT ASSISTANCE (Continued) (5)

[X] COMMAND PROGRAM SCHEDULE
[X] OPERATING PROGRAM SCHEDULE (6)

PROGRAM SCHEDULE FOR OCQMG (7)

ORIGINAL [X] CHANGE NO. (8)

DATE: 26 March 1956 (9)

BREAKDOWN OF ACTIVITY/SUB-ACTIVITY (Objectives and Workload) (10)	UNIT (11)	FISCAL PROJECT (12)	PHASED OBJECTIVES OR WORKLOAD FISCAL YEAR 1957 (13)				
			1ST QTR	2D QTR	3D QTR	4TH QTR	TOTAL
5. Continued							
c. Ea. OQMG Supervisor to Have a Current Supervisor's Manual	Coverage	2012	25%	50%	75%	100%	100%
6. Planned Mgmt. Improvement Projects by each OQMG Supervisor	Project		0	1	0	1	2
7. Coordination of Mgmt. Engg. Activities							
a. Establishment of a QM Work Measurement Panel	Project		0	1	0	0	1
b. QM Work Measurement Panel	Mo. Mtgs.		0	1	3	3	7
c. Establish a QM Management Impvt. Council	Project		0	0	1	0	1
d. QM Mgmt. Improvement Council	Quarterly Mtgs.		0	0	1	1	2
8. Exchange of Ideas							
a. Distribution of OCA Mgmt. Info.	Packet		3	3	3	3	12
b. Distribution of QM Mgmt. Info.	Packet		1	1	1	1	4
c. Circulation of QM Mgmt. Improvement	Project		1	1	1	1	4
9. Revision of QM MCIP for Trg. Mgmt. Engg. Personnel in the QM System	Project		0	0	0	1	1

OFFICE OF THE QUARTERMASTER GENERAL (1)	PROGRAM TITLE: QMC COMMAND & MANAGEMENT PROGRAM (2)	PROGRAM NO.: 4 - PART VI - MANAGEMENT (3)
ACTIVITY: MANAGEMENT ENGINEERING ACTIVITY (Continued) (4)	SUB-ACTIVITY: MANAGEMENT ASSISTANCE (Continued) (5)	
X COMMAND PROGRAM SCHEDULE X OPERATING PROGRAM SCHEDULE (6)	PROGRAM SCHEDULE FOR: OQMG (7)	ORIGINAL [X] CHANGE NO. (8)
		DATE: 26 March 1956 (9)

BREAKDOWN OF ACTIVITY/SUB-ACTIVITY (Objectives and Workload) (10)	UNIT (11)	FISCAL PROJECT (12)	PHASED OBJECTIVES OR WORKLOAD FISCAL YEAR 1957 (13)				
			1ST QTR	2D QTR	3D QTR	4TH QTR	TOTAL
10. Mgmt. Engg. Field Evaluations							
a. Visits to QM Installations	Visits to Field Installations	2012	2	2	2	2	8
b. Increase Mgmt Engg Effectiveness			0	1	0	1	2
11. Mgmt. Improvement Reporting							
a. Thru DCSLOG to Comptroller of Army	Report		1	1	1	1	4
b. Annual Report for FY 56 to TQMG	Report		1	0	0	0	1
c. Outstanding Accomplishments Bi-weekly to the AS/A (Logistics)	Report		6	7	6	7	26
d. By each OQMG Office & Division to Mgmt Division	Report		1	1	1	1	4
12. Supervision of Mgmt. Engg. Services Contract for Phila. QM Depot Factory	Project		60%	80%	90%	100%	100%
13. Office Machine Systems	Project		0	0	0	1	1
14. OQMG Mgmt. Engineering Field Representatives (2)	OQMG Consultations per each		0	1	0	1	2

PROGRAM CONTROLS FOR USE WITH MACHINE TOOLS
(Controls that Think and Act Automatically)

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Program control for factory machines is the first step to automation. This step is reasonably easy to evaluate in order to determine the financial feasibility of the proposed application. Due to the fact that this type of control tends to make a variety of specialized machines out of one general purpose machine, very little trouble is encountered in justifying such equipment.

The general concept for the use of a pre-determined program requires the machine to utilize some type of information storage means. This storage means classifies the control. For example:

1. Time or sequence program.
2. Tracer controls using physical templates.
3. Punched cards or punched tape.
4. Magnetic tape.

These storage means can further be classified as analog or digital. By analog we mean a continuous control that performs in a general or approximately specified manner. By digital we mean a control that responds to exactly specified information such as counting or working to exact measurements. It must be kept in mind that there is no fundamental difference in the accuracy of these two systems, although the word description tends to classify the digital as the more accurate of the two.

The time or sequence program type of equipment can utilize cycles of the supply frequency or second-counting techniques to determine the desired timing of an operation. This same timing operation could also utilize a motor driven cam to open and close a contact to give the desired timing interval. The first would be the digital approach and the second would be the analog approach. It is obvious that the accuracy would be determined by the size of the time increments being counted or the accuracy of the shape and speed of the cam.

The tracer control type of program equipment using a physical template is truly an analog type of equipment. In this case, we prepare a template or use a sample of the part to be manufactured and closely follow its contours with a mechanical feeler or stylus that will control a machine to reproduce a part. This type of equipment could be a brute force follower system with the stylus held against the template with a spring strong enough to overcome tool reaction. The other extreme would be a very sensitive amplified control that would exert only ounces of pressure against the template and yet, would be capable of controlling precisely a large electric motor or hydraulic system that positions the cutting tool.

A punched card control utilizing the conventional business machine card, such as an IBM or Remington Rand Card, will store digital information. However, the reading equipment used to read the card can convert this digital data to analog information for the control of the machine. This reading equipment can also supply digital information for the control of the machine and thus, be a truly digital control. These comments apply equally well to punched tape equipment, which is obviously just the same as fastening a number of cards end to end and running them over a drum rather than reading them sequentially from a stack.

Control equipment using magnetic tape can be either digital or analog. It is possible to store digital information on a magnetic tape as is done on many large high speed computers today. This information can be read out as digital information and used as such or translated into analog information for the control of the machine. It is also possible to store analog information on a magnetic tape by recording electrical voltages that are an indication of desired machine operation or position.

There are equipments of the above types available in various forms from various sources for use on manufacturing processes. I am sure everyone is familiar with the motor driven cam switch used to sequence and time processes. There are a number of manufacturers producing such equipment either utilizing the motor driven cam shaft or combinations of individual timing elements tied together to perform the desired sequence.

The tracer control utilizing a template or sample part is broadly classified into three classes:

1. The brute force or direct follower described previously is too obvious to be discussed further.

2. Hydraulic tracer controls utilizing a stylus driven valve to follow the template used to control a hydraulic piston or motor to position the tool or work piece.

3. Electrical tracer control systems utilizing an electrical control on a stylus that follows the template which will, in turn, control an electric motor that positions the tool or work piece.

A number of machine tool manufacturers utilize the hydraulic tracer system. Probably the best known and largest manufacturer of such equipment is the Cincinnati Milling Machine Company who supply the Hydro-Tel or hydraulic tracer equipment. There are also a number of manufacturers that build electrical tracer equipment, among which is the General Electric Company.

SLIDE

Here is a slide showing an electrical tracing head following a template and, in turn, controlling the X and Y axis movement of the cutting tool. This type of equipment is built three different ways: the first, single dimensional which moves the tool back and forth along a single line and depends on a continuous feed in the other axis to give motion across a work piece. The second or two dimensional control, as shown here, is arranged to follow the surface of the template at a constant speed in any direction in a given plane. The third or three dimensional control is a combination of these two that gives control in one plane plus a depth control vertical to the controlled plane.

The problems in applying this type of control to a machine are truly related to the quality of the machine as the backlash and deflection of the machine elements are a part of the closed cycle system and therefore, seriously influence the stability problems of the system. Rigidly-mounted machine parts and low values of the backlash in the gear or lead screws will permit much higher speeds of operations with a given degree of accuracy. In other words, accuracy and speed are related to the extent that for a given machine condition greater accuracy can be obtained at lower cutting speeds, or stating it another way, if higher cutting speeds are required, accuracy must be sacrificed.

The development of this type of program control has reached a state of perfection that permits cutting speeds and accuracy quite in keeping with production requirements and tool wear. I want to be sure to leave one thought with you and that is, that the accuracy and speed of metal removal is a function of the machine quality as well as the characteristics of the control.

SLIDE

Here is an equipment designed to operate a punch press from the information stored in a deck of business machine cards. It will be noted that this is a turret type of punch press with a movable table so that various holes can be punched in a sheet of metal by positioning the table and selecting the proper punch. This information for each operation of the punch press is recorded on a punched card as shown here. The X dimension is punched in inches and decimal parts of an inch. The same is true of the Y dimension. The tool to be used is recorded by number. By combining the required number of these cards, this punch press can be put through its paces to produce a complete panel without any manual operation except to put in the blank panel and remove the finished panel. This is an example of storing digital information; however, in this particular equipment, this information was used to position selsyns which are analog devices. The position feedback from the machine is also by means of selsyns geared to each motion of the tape as well as the rotary motion of the tool turret. This is, therefore, a combination digital and analog control.

It should be kept in mind that a punched tape could be used instead of the punched cards and would require an intermittent drive on the tape rather than using the sequential card reader shown in the slides.

Equipment is manufactured today using this same general principle of information storage on either punched cards or tape by using the digital information for the control of the machine. In this case, the position of the table and turret must be determined by means of a digital feedback element. This can be done a number of ways, the most common of which is to count divisions of very accurate scribed scales fastened to the table and the turret.

SLIDE

Here is a magnetic tape controlled milling machine that works on the analog principle. In this case, there is recorded on the magnetic tape a voltage that is equivalent to selsyn voltage that has been recorded in accordance with the desired position of the machine. With the same type of selsyn geared to the machine and used as the feedback element, the machine can be controlled continuously as the tape is played back on the control. A separate channel or recording is required for each motion or machine function to be performed. For example, on a lathe it would be necessary to record the cross feed motion as well as the longitudinal feed motion to completely turn a piece of work. However, in the machine shown here, which is a milling machine designed to machine airplane wing skins, 14 channels of recording have been provided so as to control all of the complex motions and auxiliary functions required for completing an airplane wing skin.

In applications of this type, the preparation of the recordings is somewhat of a problem as the motions are so complex that it is impractical to go through the manual processes to accurately record the required motions. Therefore, there has been made available a combination computer and director with which an operator can take the drawing information and prepare a magnetic tape that will control the machine. Thus, it is possible to machine practically automatically a complex part from drawing information without the use of a skilled machinist. In fact, this machine is so complex and involves so many simultaneous motions that it is considered practically impossible to operate it by hand and make full utilization of all of the simultaneous motions. Thus, it is rather obvious there will be a tremendous saving in machine time.

Another approach to this same problem would be to use a form of the director used to prepare the tape to control the machine directly. There are some advocates of this principle of control and they are building successful operating machines. Most of these types of controls use the all-digital approach to the problem and require some form of digital feedback from the machine. We have favored the magnetic tape link on the basis that one director for making tapes from the drawing information can be used to make tapes for a number of tape controlled machines. In fact, tapes could be made in a central headquarters for use on machines in a number of different factories. This is a controversial subject in the machine tool industry today and each side has about an equal number of supporters.

This controversy is closely allied to the digital versus analog controversy which will probably end with the realization that each system will find its place in different types of applications. Either system properly designed and maintained will work and give similar performance. I have covered what I believe to be the principal programming control methods in use today and have tried to give you some of the considerations involved in each of the methods. Rather than argue as to which is the best method, I believe it is best to assume that each has its place and all engineers should attempt to use the best suited programming method for their particular problem.

AUTOMATION - MANAGEMENT'S CHALLENGE

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Introduction to film "This is Automation"

Yesterday, the challenge of automation was in the area of equipment design. It dealt in the details of designing automatic equipment, transfers and controls - how to pick up a piece, move it into a machine, perform work, and move it out - do it all automatically and in the proper control sequence. The problems were for engineers to conceive equipment to manufacture parts, fully automatically.

Today, the challenge is greater for now automation requires Management to consider the whole business. Our thinking must broaden instead of dealing only in terms of automatic equipment, Management must now consider the relationship between product design, standardization, marketing strategies, manufacturing facilities, customer acceptance, etc.

We are now becoming aware that the extent to which automation - the continuous automatic production concept - can be applied to a business is dependent to a very large degree on a "way of thinking" on the part of Management. For they must provide the proper climate, attitude, and leadership in applying automation to a business. They must recognize that it affects all functions of the business - not just manufacturing and engineering alone.

Once Management has recognized the competitive challenge of applying automation to their business, just how do they go about meeting this challenge?

As we see it, there are two pre-requisites to applying automation today.

First, you've got to have a <u>desire</u> to automate. You have to want to automate as a business. You must be really anxious for it and it must have the complete understanding, backing, and enthusiasm of your associates and Management.

Secondly, you have to "get religion" - that is to say, you have to believe in the <u>continuous automatic production</u> concept. You need to understand that it is a <u>way of manufacturing</u> that begins with a "way of thinking" on the part of Management. It has far reaching effects, in that it influences your entire organization, your suppliers, and your customers.

You are all aware of how rapidly our American economy is expanding and how it is expected to keep on expanding in the years ahead--so much so that it is estimated that it will increase by some 40% during the next ten years, even though the available work force will increase by only 14%.

To meet this growing market then, and to maintain our present standard of living, we will have to increase our productivity. As our factories become more productive - and more automatic - it results in a greater need for Management to integrate the thinking between product design, standardization, marketing strategies, manufacturing facilities, project financing, and customer acceptance.

While we have always had the same kinds of problems, today they are much broader in scope and more complex.

With Management thinking in terms of the total business, the effects of automation may be demonstrated by discussing briefly some of the factors affecting it.

First, let's talk about standardization of products and product lines.

Standardization is one of the keys of economical automation. Through standardization, low volume parts may be used on common components thus providing the volume necessary for automation. But this is only the beginning, for through standardizing our product lines, we will have fewer models, and with fewer models of a particular item, we will be less likely to run out of stock. This means greater customer satisfaction and convenience, and faster turnover will mean lower inventory.

The process of standardization starts with the combined efforts of marketing, engineering, and manufacturing. The engineer must first think in terms of standardized components and equipment. Then, the marketing people must sell it to the customer. The customer must be shown that he can obtain more value, better quality, for less money, by purchasing a standardized item. Standardization is the only solution whereby we can fulfill the market demands during the next decade - yet we continually underestimate what standardization can do for us and business as a whole.

Next to standardization, probably the most important factor affecting automation is simplification. Simplification of product design, of manufacturing process and equipment, and of business procedure. Through simplification of product design, many manual operations may be designed out of the product and at the same time, the product can then be designed for automatic manufacturing techniques.

New office machinery available today offers many opportunities for the simplification of routine clerical and accounting procedures. Simplification, like standardization, is one of the keys to automation.

In the manufacturing area, we should be on the outlook for new and simplified processes, and new equipment should be designed simply so that it is easy to maintain and service.

This brings up the next important point. The urgent need to train people - to upgrade their skills. In many industries today when a new automatic machine is installed in a plant, adequately trained people to run them are not available, nor are there adequately trained people to service them. When an automation program is started, we should at the same time, start to plan to upgrade the skills of those who will be responsible for operating and maintaining the program. This applies equally to Management, office personnel, and the factory worker. The importance of recognizing the need for upgrading the skills of our people and then helping them do it, can often mean the difference between success or failure of an automation program.

In discussing automation, the question always comes up regarding manufacturing facilities and equipment. Businesses with standardized high production lines generally think of equipment in terms of their "product". Equipment is obtained to manufacture a given product with a given design life expectancy. The equipment is flexible between narrow limits and it has only the necessary controls and features.

Businesses that have a large variety of products generally think of their equipment in terms of "processes". This type of equipment is completely flexible between broad limits and permits the job shop operator with high enough volume of similar items to purchase fully automatic equipment.

Management's decision as to which type of equipment to purchase - in terms of "product" or in terms of "process" - will become increasingly important as we progress in automation.

Another area which is important to those businesses contemplating an automation program, is business planning. Many businesses today are already meeting the challenge for better planning - both short and long-range. The need for better planning, and taking the time to do it, can't be over-emphasized. Management can delegate the planning project to a group of its most competent people, but Management can't delegate the final decisions.

Before concluding, I would like to re-emphasize the importance of the attitude of Management's role in the realization of the industrial automation. For it's up to Management - Management with

vision, enthusiasm, and imagination - to apply this way of manufacturing to their businesses. They must determine the degree of automation that their business requires and can support economically. And then develop an overall progressive step-by-step program and see that it is properly carried out. Management must also determine what changes will be made, whether in product design, standardization, manufacturing processes, marketing techniques, or plant layout. Some, or perhaps all of these may have to be altered in order to apply automation successfully.

While the physical results of automation may be seen as machines and equipment on the factory floor, it must begin as an attitude in the minds of Management. We cannot just add controls, gadgets, transfers or hardware without a well-thought out program. Many processes today can be automated - the question is not whether they can be automated, but rather, "why" and "when" should they be automated? These are some of the challenges today for Management.

Earlier, I said that one of the pre-requisites to applying automation to a business was that you first had to "get religion" - that is to say, you have to believe in the continuous automatic production concept and understand that it is a way of manufacturing.

Now just what is this continuous automatic production concept, this way of manufacturing?

To answer that question, we have a film that we would like you to see, entitled, "This is Automation".

PROBLEMS IN WORK MEASUREMENT

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Recent events, notably the Westinghouse strike, have thrown certain aspects of timestudy and its resultant standards into strong relief. Consequently I feel that my remarks have sufficient timeliness to override their lack of originality. I can suggest no quick or easy solutions to the major problems of timestudy, for there are none. There are, however, courses to follow and matters to be understood. My only hope is to bring a little perspective to an intricate situation - a situation which must eventually be dealt with by a meeting of minds, rather than through a Pyrrhic victory following a political and emotional battle between labor and management.

In speaking of the problems of timestudy, I realize that these are innumerable and, whether trivial or not, each is of consequence at the time. However, large or small, they all stem from two basic dilemmas.

One of these is capable of eventual solution by elimination. The other is not, and must be lived with. The first relates to the technical difficulty of maintaining consistent work-standards; the second relates to the fact that the numbers produced by time-study must be treated as if they were accounting numbers when actually their nature is statistical or actuarial. The two problems are closely interlocked but lend themselves to separate consideration.

Let us look at the first problem - that of maintaining consistent work-standards. You will note that I did not say: "correct work-standards". In this area "consistency" is a much more significant term than is "correctness". Also, consistency is the most desirable quality in work-standards. Consistency is subject to proof, while the correctness of an item, being a matter of relationship to a standard, is an arbitrary concept and can only be substantiated, in the last analysis, on the basis of consistency. Perhaps I should say that correctness is here used in the sense of propriety, and not in the sense of accuracy which is something else again. Historically the problem of consistent standards has gone through two phases and is going through a third that in some ways so resembles the first as to suggest a cycle.

The first of these was the pre-timestudy era of the piece-rate, set by devious means which I do not need to relate. On the whole it was a matter of personal relationships and deals between the

foreman and the operative. A rather dubious modus operandi evolved with which you are all familiar, at least by hearsay, but one can hardly say that it was notable for either correctness or consistency.

Both sides abused the system, if it can be called such, and there developed a peculiar state of affairs - a combination of guerrilla tactics and passive resistance that resulted in a sort of stalemate. At least one would be put to it to say who won.

Largely as a result of this, timestudy came to the forefront and the practice of guaranteeing standards and even piece-rates became the vogue. We had great confidence in our timestudies and we sincerely believed that the workers were entitled to some assurance that their rates would not be subject to arbitrary reductions if earnings should exceed a certain level. As a result we proceeded to guarantee our work-standards in perpetuity so long as the job remained unchanged. Just what constituted a change, and how much of it could be taken to justify a revision of the standard was rarely specified.

All in all the guarantee, while probably unavoidable, turned out to be a rather ingenuous codification of faith and sportsmanship. Nevertheless it served its purpose of stabilization for a couple of decades, before the truth dawned, in a vague and ragged fashion, that guaranteeing something that does not always lend itself to a guarantee can create embarrassing anomalies.

A guarantee of the type we are considering, if it is to have any validity, must be supported by a clear and detailed statement as to what exactly is being guaranteed. In the early time studies the descriptions of method were frequently so general that they amounted to little more than an identification of the end result of the job.

Within such extremely broad specifications there was room for wide variations in methods and in physical conditions. It was not uncommon for a work-standard to become "loose" by two or three times. It was possible, but less likely, for a standard to become "tight". However, the pressure of operator complaints plus a sense of justice, naturally tended towards the prompt adjustment of tight standards.

When I said that a standard cannot always be guaranteed, that, of course, is not strictly so. However, the continuance by guarantee of a time-standard that does not jibe with the details of the task being performed falls in much the same category as a fanciful election bet. It may be possible to honor the guarantee, but doing so creates a nonsensical situation. On a one-time basis this may not be serious, but when it is introduced into an industrial system of tasks and payment it leads to an inequitable and, consequently, discriminatory state of affairs that is untenable.

Eventually the situation must be corrected, for the benefit of the parties concerned, as well as for the benefit of the economy at large.

The situation is untenable because it actually condones avoidable waste. Although a marginal amount of waste may be tolerated as a matter of political or other expediency, it is a fact that waste in any form is theoretically inadmissible in the economic philosophy to which this continent is committed and expediency or not, there are always limits. We are irretrievably committed to a course which requires the compounding of technological gains in the form of an annual increase in the productivity rate of some 2-3 per cent. This has now become a matter of actual national survival and opposition to it is barely this side of treason.

The waste that results from a man producing less than he could justly be asked to produce is no different from the actual squandering of physical materials. The latter is rarely condoned, but the former is often treated with tolerance, with complacency, or even with approval. Certainly attempts to retrieve the waste of manpower inherent in loose work-standards are opposed by Unions and their membership. Clauses in Union agreements ostensibly designed to support necessary changes in standard are almost always more restrictive than permissive. Even in the absence of formal rules, management is reluctant to move in on loose standards, partly from fear of the inevitable complaints and partly in consideration of past guarantees.

All of these matters relate to one of industry's most universal and serious problems. It is certainly the timestudy man's greatest headache - the so-called "creeping change". It is a form of waste that waters down living standards by billions of dollars a year. The term "creeping change" is almost self-explanatory, but it does cover a wider area than might be supposed. In general it refers to gradual and almost imperceptible changes in motion pattern whereby the amount of work done is less than would be justified by the respective work-standard.

The causes of this reduction are varied and may have some bearing on the degree of difficulty encountered in correcting the standard. For instance, if it can be shown that the work content has been lessened because of improvements in the physical conditions of materials and equipment, it will be easier to adjust the standard than if the change was solely one of a simplification in the motion pattern. Also motion changes introduced by management (consciously or not) are in a different class from motion changes introduced by the operator (consciously or not).

Some 25% of current arbitration cases relate to this problem and the number is growing, although perhaps not as rapidly as their

significance in labor relations. If you have read any of the recent cases you will have been amazed at the innumerable variations. For instance, there is the problem of deciding if the original standard was right to begin with; whether distinction has been drawn between the exhaustion of the learning period and a basic improvement in the motion pattern; whether the new method was originally suggested by the timestudy man and rejected by the operator and the foreman; whether a specific operator has a unique aptitude, or whether his method is teachable; whether the operator is a normal operator - and so on ad infinitum.

Two aspects of all this tend to stand out. One is the almost certain inadequacy of past documentation, i.e. the element times obtained in a re-study point to methods changes, but the original study is too sketchy to permit their being pin-pointed. The other aspect is that the passage of time is a major factor and that squatter's rights set in quite early in the game.

The latter, of course, suggests a constant and immediate review of standards by a timestudy staff that is fully adequate in both numbers and competence.

The former (inadequate description), it seems to me, must lead inevitably to the eventual acceptance by both labor and management of a principle which now gets short shrift. It is that the work-standard and the details of the timestudy must form an indivisible unit. The study provides both the specifications and the standard and any change in either must be matched by a change in the other. If this principle of unity were accepted, the change in standard would be dealt with no matter how small, no matter how or by whom it was introduced, and no matter how or when it was disclosed.

This clearly means that the specifications must be complete and unambiguous. This need has long been recognized, but the lack of it, especially in old studies, remains acute. Few companies have been successful in avoiding the problem and I know of none that have really solved it. We do not have time to explore it, except to note that the proper use of predetermined motion-times is a long step in the right direction - technically that is.

However, the human relations problems still remain. One would like to think that in view of the impelling need for the prevention of waste and for the avoidance of discriminatory standards, it should be apparent that Labor and Management must soon come to terms on the principle of truly linking the standard to the specifications. When I say come to terms, I am not thinking of bargaining in the usual sense. In most cases it has not yet attained maturity, ranging as it does from Oriental-type haggling to the most barefaced exercise of duress.

In this respect I daresay some of you were perturbed by a recent statement in Time. It is not distorted by removal from its context. It runs: "G.M. and Ford agree wholeheartedly with the U.A.W. that timestudy is not an exact science, but a starting point for bargaining about base-pay and incentives".

I am not at all sure that I know what this means, but it appears to make little sense. I would agree that timestudy still leaves much to be desired, and that there is an area in which bargaining is admissible. That area is the area of money - not the area of measurement no matter how crude.

One can haggle with the butcher over the price of a pound of steak, but it makes no sense at all to haggle over whether the pound is a pound. That can be ascertained. Also it makes no sense to jiggle the butcher's arm while he is doing the weighing.

In recent years these matters have been coming to a head. Management has been trying to find ways to bring standards more into line with reality. Unions have tried to protect the status quo without too much concern for the correctness or consistency of rates. As a result we have a great variety of timestudy clauses in Union agreements. While lip-service is paid to the mutual need for equitable standards, current clauses are almost all more reactionary than constructive. None of them is wholly satisfactory, particularly to management, and some are incredibly bad.

The clauses divide into three types. The first purports to be technical and attempts to prescribe the details of the timestudy methods. Mostly the attempt settles down to prohibitory items and never gets to setting out the timestudy procedures in full. As a matter of fact it would be completely impracticable to do so within the confines of a labor agreement. Consider the problem of dealing with process allowance; varying proportions of idle operator time while a machine is running; machine interference; over and under assignment; rating; rating on machine controlled jobs; fatigue, cyclical and non-cyclical delays and so on; all set out with such clarity that arbitration would not need to be invoked.

The essence of this is that a partial description of timestudy is no description at all and would be better omitted altogether. Certainly the practice of bargaining over isolated bits of timestudy procedure (e.g. fatigue allowance) is to be shunned. This can only deteriorate into manoeuvering for concessions, to be increased at a later opportunity.

A second and commoner type of clause ignores technique altogether and confines itself to restricting the rights of management in setting or changing standards. Unlike the first type, such clauses are not impracticable. They are, however, objectionable for, being

inspired by a desire to protect rates no matter how soft, they are essentially discriminatory. They discriminate not only against the company but also between operators in that they tend to perpetuate inequalities in standards.

The third type of clause appears to cut the Gordian knot merely by stating that a standard must yield a specified earnings potential.

At first glance this looks like a sound idea. In fact it probably is a sound idea in theory. However, in practice, it usually fails because it moves right into the area of the second basic timestudy problem I mentioned at the outset. It relates to the difficulty familiar to all timestudy men who are forced to establish statistical numbers and then to apply them to individual cases. It is the old problem of a generality applied to a specific case.

The problem occurs in the technical processes of timestudy as well as in its application to incentives. For instance, in actual study it is almost impossible to obtain a true and undistorted statistical diagram of even the simplest element. Consequently we resort to the much maligned practice of rating. In this way we attempt to place an observed time in its proper position in the normal statistical distribution curve. Similar problems arise in the evaluation of fatigue allowances, incidental delays and so on. The end result of this is a time standard that may well be correct from a statistical-mathematical standpoint, that may be suitable for at least fifty per cent of those to whom it applies, and yet may in a real sense be incorrect for the first individual required to work on it.

The situation is a familiar one and I do not need to labor it here. It exists in many phases of human activity, but it takes on unusual significance in the field of timestudy and incentives.

Obviously it cannot be eliminated by any refinement in technique. In fact refinement in precision and consistency would probably sharpen the problems of application.

When a difficulty cannot be removed, the next best thing is to avoid it, or find ways of offsetting it. In the incentive area full use should be made of selection and training, in order to avoid putting the wrong person on a job and in order to see that correct methods are being followed.

This whole subject of statistical numbers applied to individual cases is far too complex to permit us to do much more than mention it here. However, this summary treatment should not be taken as a measure of relative importance. Actually the matter is of constant concern to all engaged in timestudy and incentive plan work. It underlies most of the difficulties in that field. At least if there were no spread in human stamina, speed, reactions and so on, time-study would be immeasurably simpler.

Rather than get into technicalities, may I conclude by summarizing.

One of the most serious problems faced by management and labor is the establishment and maintenance of valid work standards. There is no short cut and no easy way, yet the matter will become more pressing as timestudy techniques become more precise and as Unions begin to take more of a hand in the matter.

We have in the past tried to deal with the problem unilaterally. It is not likely that this will continue. Probably it is not even desirable that it should. However, it would be most undesirable to attempt to deal with it through the channels of orthodox bargaining with each party jockeying for position and hoping to make a better deal in the next round. In other words, it must not be a matter of political compromise but rather one of objective decisions made on technical and impersonal grounds.

Both parties should strive to achieve standards that are correct and consistent and should be prepared to change those standards immediately if at any time they do not reflect as closely as is humanly possible the amount of work that is to be done. The specifications and the rate should be an indivisible unit. I am afraid that this is far in the future and that both parties have a great deal of past to forget. Eventually I believe it must come to pass in the interests of everybody concerned - management, worker and general public.

As far as the Unions go, progress towards an objective solution will be slow. Unions must function as political bodies, and there is some doubt as to whether it would be sensible for them to act otherwise. However, there are times when the opportunism and short range expediency so prevalant in politics must be set aside. I believe that in the need for realism in work-standards that time has been reached.

In spite of the pressures to which they are subjected, the leaders and the members of unions must eventually accept the fact that the advantages bestowed by technology entail certain responsibilities. Condoning and perpetuating waste is not one of them. To a great extent proper work-standards are a guarantee that the benefits of technology will not be dissipated, or unfairly distributed.

This places a great responsibility on the members of A.I.I.E. to improve their techniques, to keep human values to the forefront without becoming maudlin or discriminatory, and to maintain a professional integrity at all costs.

INDUSTRIAL APPLICATIONS OF M.P.

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When you begin discussing the area of mathematics in the field of management, one problem that is always encountered is that of communication.

For those of you who have mathematicians in your company, you are well aware of the problem. The mathematician doesn't speak your language, and you, as a manager, do not speak his. Such conditions are not unusual since special languages develop and exist within each specialized type of activity, be it industrial engineering, physics, electronics or mathematics. For that matter, industry itself has its own language, "shop parlance".

One of the purposes of this paper will be to try to translate the language of the mathematician into industrial terminology. Two examples of applications have been chosen for exploration which require differing degrees of understanding of the techniques of mathematical programming.

However, before getting into these applications another problem bears comment. A common question that I am asked is: "Who should do the work?"

To answer this question, let's compare the types of thinking involved and the differences in approach which the mathematician or the industrial man brings to the problem.

I think that it will generally be agreed that the mathematicians' primary attack on a problem will be along mathematical lines. On the other hand, the manager will say to himself, "Here's a problem that needs a solution. Which technique can I employ to get a workable and good answer?"

The distinction may be slight but it is an important one.

First of all, it means that the manager is interested in solutions rather than the method. It also means that the manager will muddy up the mathematics and make the equations inrecognizable, if that's what he needs to get the job done. It means that the manager doesn't care if the mathematics is pure and beautifully complete, and finally, it means that the manager doesn't give a darn if he can't prove that his solution is general and can thus be applied to all his competitor's similar problems.

In brief then, we can say that the manager is interested in results, and the mathematician in the formal structure.

Now then, let us not throw the mathematician out completely. He has some wonderful tools which we can well learn to use and apply.

But as soon as you try to apply them, you get into another problem: The mathematician contends that this stuff is too deep for you to comprehend. You may be smart enough to run a hundred million dollar operation, but not smart enough to solve your own problems -- at least not with his esoteric bag of gems.

For a more detailed exploration of this philosophy, see "How to Invent a Profession" by Alvin Brown, Journal of Industrial Engineering, Volume VI, No. 3, May-June, 1955.

The net result of this downgrading of management ability, has produced a quest for mathematicians, of any calibre, so that the company can be led back into the light. And in at least one sense, those companies who have been responded to this propoganda will be led into the light.

Having hired the mathematicians, the next question arises: "Where do these men belong?"

The Operations Research protagonists suggest a pos'tion as near to the top as possible. Such a position, incidently is desired by every function operating in industry today. It is always nice to present your views where they will be assured an adequate audience. Unfortunately, presidents have other duties besides listening to technical discussions. The OR people maintain their stand by pointing out that their field is to be an overall study of management, with no shackles attached to their men. They are to be free to roam and to make presentations.

The disadvantage of starting at the top is that sweepingly new concepts that are initiated at the top are notorious for the fact that they encounter increasingly greater immobility as they move downward. The operating people need to know and to be sold before they accept and use.

This disadvantage can be overcome by properly orienting a wide range of people with new techniques through short indoctrination programs. Longer training programs can then be given to the people in the various divisions who will be called upon to apply and evaluate the new techniques in their own division.

Through such programs, ideas originate at the top and applications and developments originate in the operating groups.

As the operating groups begin to round up the really valuable areas of application, they will encounter areas in which help is needed, and what more logical area should they go to for assistance than a group within their own firm?

A procedure much like the one just described, of orientation - training - application - assistance, is presently being used by the Philco Corporation in Philadelphia.

As a means of supplying technical know-how to operating groups who request it, many firms are moving in the direction of captive-consulting groups, or setting up a management engineering branch.

The management engineering branch has the important position which the OR people want, but converts OR into technical know-how which the management engineers can apply and evaluate. Such a branch is usually composed principally of industrial and cost engineers who are well acquainted with management problems and practices. By definition, this means that the management engineering branch is composed of "application" people who know operations research techniques, along with many others, and whose purpose is to disseminate usable ideas to the operating groups down the line, and also to offer assistance where required.

The name "Operations Research" implies research on operations. Since research is generally conceded to be exploratory and slow moving, few firms can afford the luxury of such groups per se. Far better to assign such studies to university groups and other research organizations.

The distinction to be made, then, is that industry, your own company, is primarily interested in applications internally and research, externally.

The average firm needs application engineers for these techniques before anything else.

A good applications engineer constantly meddles in the work of the research engineer, and a successful one is always accused of prostituting the works of pure research.

Applications engineers are hard to come by, but one thing is obvious: we can train a man in modern mathematical techniques such as Mathematical Programming in a matter of weeks, but to make a good management man out of a mathematician may take years. It took you years to reach your present state of effectiveness; would you expect others to learn it in weeks?

One other question remains to be considered before moving on to applications: "Where can you learn these new techniques so that your own people will be able to do the work with a minimum of assistance?"

There are principally two ways in which new techniques can be learned and assimulated:

1. Through attending concentrated, applied training programs in the areas of mathematical management, such as those offered by our own firm, or

2. Through conferences, in which you can find out what others are doing, and possibly visiting such firms.

Our own training program in Mathematical Programming is over two years old and features a large number of applied case examples to illustrate the techniques presented. Our own experience has been that the best results, the best applications, have been made by those conferees who are short on theory and strong on practice.

The conferences are useful in picking up new applications of old techniques and in seeing what other methods show promise.

Now we are ready to discuss applications.

The points just discussed have been put forth for a reason: It is my desire to point out some applications that have been made and show you that you can do the work.

The first application is the simplest to understand, and apply, but the second application requires very little additional knowledge of mathematical programming to make it workable.

MACHINE ALLOCATION

Mathematical Programming finds an important application in machine allocation. The procedures and principles are readily applicable to this type of problem.

Since the first installation was made at SKF Industries, Inc., in the automatics department, many similar applications and studies have been made to machine shops, rim plants, forge shops, tube mills, and miscellaneous other equipment. Savings have run as high as $100,000 a year and production increases as high as 20%.

Allocating a number of orders to various machine groups is a problem that should normally be solved by precise mathematical methods. Although these methods give precise or exact answers, they are tedious and cumbersome to work with. Solution by these methods is time consuming and even use of computers may not be practical, because of the mass of data involved, and the exigencies of time.

Production planning requires quick answers to meet the constant changing conditions. Rush orders come in which must be produced as quickly as possible. The schedule clerk must allocate the rush order to a machine group. Is it better to assign the rush order to the first open machine or is it better to tear a job off a machine and put the rush order on it? How are machine breakdowns best handled? These and a number of other problems such as tooling, stock and hunting season all tend to create a state of confusion for the schedule clerk.

Although a company may freeze a schedule on a weekly basis, there is nothing frozen about it. The schedule, from the time it is frozen, is in a constant state of flux.

Out of this condition of chaos, systems of production control have been developed which try to create order through planning.

The schedule clerk, or the foreman, makes the best decisions he can with the time and data he has on hand.

Problems such as these which could and should be solved by the proven methods of Mathematical Programming are not because of the time limitation.

Recognizing the problem as a mathematical programming application leads one to search for methods which will give solutions within the time limits allowed. In other words, we take our first step in muddying up the precise mathematics. We are tossing off the cumbersome mathematics, but retaining the principles, which you will see are highly effective. A "quick" method of solution is developed.

Such "quick" solutions must satisfy the conditions of the shop and apply the principles of programming. Minimum cost or least overall running time may be part of the conditions of the solution.

Early analysis of machine allocation problems showed that they could be solved by sophisticated inspection techniques, if the data were properly organized and formulated. Such a technique is the index method. The index method gives rapid approximations to the problem. Since the solutions are approximations, the answers are not always exact, and can be quite far from the best answer. Because the procedure is based on inspection, the method relies upon the ability of the operator for its degree of accuracy. An operator, or clerk, who is poor at perceiving relationships, or becomes careless over a period of time, or who is rushed for time will tend to give poorer answers than another operator working under the best conditions.

The index method meets all the requirements of time. In addition, it can be solved by an ordinary clerical worker and can be taught in a few minutes. The value of its use cannot be questioned. Compared to standard scheduling procedures, the index method is sufficiently good as to produce the results just cited. The index method, even under poor operation, will give you the cream of the total savings, at a very economical price of operation. In our studies, the additional savings can be saved only at a price out of all proportion to the results.

Once a workable method has been developed, such as the index, refinements are naturally sought which will control the accuracy of the answers. These are developed by the operating personnel who make the procedure work.

THE PROBLEM - Illustration of standard operating procedures and Mathematical Programming principles.

For purposes of illustration a very small example has been chosen for presentation here. The method described is fully general, however, in that it applies to much larger problems in the same way. Larger problems have the advantage of offering a much greater number of choices and hence much better chances for improvement.

I The Standard Procedure:

The procedure described here is true of most companies that have a choice in assigning work to machines. It is true, also, whether the assignment is made in the planning department or by the foreman.

Machines are normally grouped together into classes of machines. The standards department considers several machines as a group if each machine in that group has the same time standard for all orders. In other words, in setting a standard, the standard need only be set for one machine in a group. It is applicable to all the machines in a group. On the other hand, standards will vary between machine groups.

The schedule clerk, similarly, builds his schedule by machine groups and will usually have a separate sheet for each group. The sheets stapled together constitute the departmental schedule. Job tickets are then written up for each order and the ticket is sent to the shop. The ticket will specify the machine group and may even specify the specific machine in the group on which the order will be run. The actual procedure for assigning work to individual machines within a group will vary depending upon whether the planning clerk or the foreman does the sequencing for setup savings.

A procedure for minimizing setups on sequencing has been developed which ties in directly with the procedures discussed here. The setup procedure will not be described in this paper since it constitutes an additional aspect of the problem.

The allocation procedure to be discussed is concerned primarily with the assignment of orders to machine groups. From here on, it will be assumed that the machines in the plant have been grouped as described above. The word "machine" will be used interchangeably with "machine group" and will mean a group of machines having the same standards. The process applies in the case of estimated times as well as standards.

In loading his schedule, the schedule or planning clerk must stay within the limits of his available machine capacity for the period covered by the schedule.

The raw available capacity of the machines is adjusted by utilization figures.

For a one week scheduling period working one shift a day, there would be 40 hours of raw available time per machine. If there are ten machines in a group, the machine group will have 400 raw available hours per scheduling period.

The utilization of this particular machine group has been studied and found to be 75%. Therefore, the 400 raw hours are adjusted by .75 to get 300 hours as the available capacity of the group. The schedule clerk uses the 300 hours as the limit to which he can load the machines.

For consistency throughout, utilization will be defined as production plus setup time divided by the raw available time. Some companies use this definition already. Other companies do not include setup in the utilization figure. Utilization figures should be maintained and kept up to date. They are invaluable in building accurate schedules and also help pinpoint certain conditions which reduce the productivity of the machines.

There are a number of ways to obtain these figures. One is by means of stop watch studies. Another, which is more accurate over the long interval of time, is work sampling.

All machine capacities discussed here will assume that a utilization figure has been applied.

Efficiency must be applied to the standards to get an accurate schedule. Many standards are set so that the operator can produce from 20 to 30 percent over the standard. This increase

over the standard production rate represents the basis for the incentive. Hence, if the standard represents 100%, the operator makeout may be 125%. This operator makeout is the efficiency of his production. The standards layout book may show, for example, that a part can be produced at the rate of 200 pieces per hour. If the operator's efficiency is 125%, his actual production will run 250 pieces per hour. Hence, efficiency must also be considered in building accurate schedules. Again, it will be assumed that this factor has been considered in the case to be discussed. Some companies divide efficiency into the standards for use in the planning department.

The schedule clerk will usually process the orders as they are received in the department. As he receives an order for a certain number of pieces, he looks up the time in the layout book, multiplies by the number of pieces and adds in the average setup time. He then assigns the order to the fastest or best machine by writing it on his schedule sheet for that machine.

The process is continued until the best machine is loaded. New orders coming in are then put on the next best machine, and so on until the weeks assignments are completed. When he assigns work to other than the best machine, he may or may not have standards for first and second alternates. Some layout books only list the best machine standards. This is done so that as much work as possible is run on the best machine. If alternate standards are not available, the work is assigned to alternate machines, usually, on the basis of a ratio. In other words, if the alternate machine is approximately twice as slow as the best machine, then the best-machine time is multiplied by two to get an approximate time for the alternate. This process can lead to great inaccuracies as will be seen later. When alternate standards are given in the books, then these standards are used to compute the production time for the order.

It is frequently the case, even though only the best machine standard is given, that the order has actually been produced on a number of machine groups in the shop. Many times, standards have been set for work that has been produced on alternates, even though such standards do not appear in the layout books. Someone in the shop has a record of these figures.

The procedure for assigning orders just discussed can be easily illustrated.

In the illustration there will be three machine groups which will be numbered 1, 2, and 3. Orders, as they are received, will be in alphabetical order. Order A is the first order received, B the second, and so on.

Since a weekly schedule is built, the available times on these machine groups are 30, 25 and 50 hours, respectively.

Order A comes into the planning department and is for 100 pieces. The clerk looks up the layout for this order and sees the following data:

Part No. A

Mach.	Pieces/Hr.	Setup Time
1	50	6 hrs.
2	12.5	4 hrs.
3	8-1/3	3 hrs.

(All times have been adjusted for efficiency)

He computes the total running time and adds in the setup time. The setup time represents an average setup. It can be seen that the best machine will depend upon the relation of setup time to running time. For 100 pieces, machine #1 is best. For ten pieces it would not be best. Some companies either overlook this relationship or introduce artificial break points. In other words, an order of a certain size or larger is to be produced on a certain machine group. Setting up the data as shown, will enable much more accurate solutions to assignments.

The order A is assigned to machine #1.

Order B is for 200 pieces. The data is given below:

Part No. B

Mach.	Pieces/Hr.	Setup Time
1	66-2/3	6
2	40	5
3	16-2/3	2

Naturally, these data figures represent only a part of the total information of the layout sheets. Such items as operations departments, secondary operations and so on have been left out. If machine #2 does not perform identically the same operation as machine #1, this can easily be included in the overall solution. Such cases frequently occur in transferring work from multi-spindle to single spindle automatics.

The order B is assigned to #1.

Order C is for 72 pieces and has the following data given:

Part No. C

Mach.	Pieces/Hr.	Setup Time
1	24	6
2	9	4
3	8	3

Order C is also assigned to #1. At this point the schedule sheet for #1 will look as follows:

SCHEDULE SHEET

Machine #1 Week of 6/22

Avail. Hrs. 30

Order	Qty.	Hrs. Load	Misc.
A	100	8	
B	200	9	
C	72	9	
		26	

Order D, for 160 pieces, takes a total time (including setup) of 10, 10 and 11 hours on machines 1, 2 and 3, respectively. Since assigning D to #1 would overload it, order D is put on #2, which is the next best machine. (Actually, in this case #2 takes the same time as #1.)

Order E, for 195 pieces, takes a total time (including setup) of 8, 12 and 13 hours on machines 1, 2 and 3 respectively. Like order D, E cannot be assigned to #1 without overloading, so it is assigned to #2, the next best machine.

The schedule sheet for #2 now is filled in as follows:

SCHEDULE SHEET

Machine #2 Week of 6/22

Avail Hrs. 25

Order	Qty.	Hrs. Load	Misc.
D	160	10	
E	195	12	
		22	

Both machines #1 and #2 are practically loaded with the exception of being able to assign small orders to them. In addition, part of one order on #2 could be run on #1 if the order were split between two machine groups. Usually splitting orders is not advisable because of the long setup times. The setup times may exceed the savings in running times. For example, running half of order E on #1 may save about three hours running time, but would add perhaps six hours setup time. (Assuming six hours setup on #1 and four hours setup on #2 for order E.)

Furthermore, the setup time, alone, would probably overload either machine, preventing the work from being completed when promised.

If the date at the top of the Schedule Sheet represents the week the work was promised, then the schedule as illustrated has kept within the promise dates.

Another point should be made in reference to the procedure being described: Although the example, here, describes the orders as if they arrive in succession, it may well be that the order A arrived eight months ago. At that time, the Order A was requested for production the week of 6/22. Similarly, B may have arrived six months ago and was wanted for production the week of 6/22. The time lag on incoming orders does not effect the ultimate principal being discussed. Orders can be cancelled or rush orders moved up, but in essence the procedure is the same.

Order F, for 85 pieces, runs on #3 in 15 hours. The other times need not have been looked up since it is known that #1 and #2 are loaded. For reference purposes, however, the times on #1 and #2 are nine and ten hours respectively. Order F is automatically assigned to #3 when it is received.

Order G is for 66 pieces. The standards data is shown below:

Part No. G.

Mach.	Pieces/Hour	Setup Time
1	11	6
2	6.6	4
3	3	3

Since #1 and #2 are known to be loaded, the total time is computed for #3, where order G is assigned.

The Schedule Sheet for #3 is given below:

SCHEDULE SHEET

Machine #3 Week of 6/22

Avail Hrs. 50

Order	Qty.	Hrs. Load	Misc.
F	85	15	
G	66	25	
		40	

None of the machines has been overloaded and the whole schedule can be produced within the specified period of time. As such, the above assignments to the machines constitute a practical, workable schedule. In addition, it would seem to be economically sound.

II MATHEMATICAL PROGRAMMING

Without changing any data or introducing any new information into the problem, this section will show how the concepts of mathematical programming are applied.

A table which lends itself to mathematical manipulation and solution is called a matrix.

Such a table can be readily formulated from the data just covered.

One of the main values of mathematical programming is that it forces one to assimilate and formulate the data of the problem in an organized way. In most cases, as you will see here, there is very little, if any, additional data required over what is presently available. The basic difference is the way in which that data is used.

The matrix below is very similar to the regular method of building a machine load. The machines are listed across the top and the orders down the left side.

The basic difference is that all alternate times are shown, including the best time. These times were taken directly from the data discussed in the standard procedure.

Order	MACHINE		
	#1	#2	#3
A	(8*)	12 (1.5)	15 (1.9)
B	(9)	10* (1.1)	14 (1.6)
C	(9)	12 (1.3)	12* (1.3)
D	10	(10) (1.0)	11* (1.1)
E	8*	(12) (1.5)	13 (1.6)
F	9	10* (1.1)	(15) (1.7)
G	12*	14 (1.2)	(25) (2.1)
Avail.	30	25	50

Table 1.

The circled figures represent the actual assignments that were made using the standard procedure. A check back to the schedule sheets for #1, #2 and #3 will quickly verify that the circled figures correspond directly to the schedule sheet assignments.

The other figures represent alternate total times that were discarded in making the assignments.

The starred figures represent a reallocation of the weeks work using the index method. You will notice that every order is starred for only one machine. Furthermore, if the starred figures are totalled for every machine, the sum does not exceed the available capacity.

Hence, the starred solution meets all the requirements specified earlier.

The total time to produce the week's work based on the circled assignments is 88 hours. The starred solution can be produced in 71 hours! A savings of 17 hours!

This means that 17 more hours of work could be produced in the same scheduling period with a resulting increase in profits and better customer deliveries.

Although the example chosen is fictitious, it is based upon actual experience in applying these techniques to industry. Industrial schedules are larger and more complex, but the procedures are the same and the savings result directly as above. For a larger schedule taken from an actual plant study in the government arsenal, see page 29-16.

The stars are based on the index method as mentioned earlier. The little numbers next to the production times are the index numbers. These index numbers are found by dividing the best machine time into each of the alternates. In the case of A, eight is divided into 12 to get 1.5 and into 15 to get 1.9. Thus, the index numbers represent the percent increase that is incurred as a result of shifting an order from the best machine. Hence, the orders to be shifted from the best machine are those that involve the least increase in ratio. A check of the starred figures will show that such a procedure has been followed.

Again, in a small example, it is just as easy to solve the problem by direct inspection. Larger problems, however, demonstrate the advantage of these index numbers. They are a direct guide to solving the allocation. It is an inspection procedure, however, as was mentioned earlier. As such, it offers no guarantee that the solution will be a minimum.

Another small example taken directly from a shop schedule is useful in illustrating the solution.

ORDER	MACHINE GROUP		
	1	2	3
A	(85)		100*
B	90*	(87)	
C	90	85*	(130)
Avail. Hrs.	90	90	200

As before, the circles represent the assignment by the standard procedure; the stars represent the assignment by inspection. The standard assignment followed the pattern described in that section. Actually orders A, B and C were scattered among several hundred and the condition above was not obvious. The saving by the reassignment is 77 hours!

The standard assignment has two orders out of three on the best machine. The programming is an attempt to run everything on the best machine only. As illustrated, such is not the case.

Another thing is that in one instance of application to a plant, the men in the shop complained that we were not doing as good a job as the standard procedure. They pointed out that they were running less work on the best machines than previously. However, when the company ran a cost variance report and computed the savings for six months, these men were quickly satisfied.

RULES FOR APPLYING MATHEMATICAL PROGRAMMING PRINCIPLES:

1. Assign (circle) every order to best machine.

2. Add up load assigned to each machine.

3. Compare load to available capacity.

4. Transfer any overload from best machine to next best on the basis of the indices. For example, an order with a 1.01 index would be transferred before an order with 1.5 index. Hence, the transfer of overload is always based upon starting with "cheapest" transfers and working toward most expensive.

Large schedules involving 250 orders with over 100 machines can be handled in this way in less than three hours. Expected savings: Better than 10% of total production time, based on companies presently using method.

AN ACTUAL CASE

On the next sheet is an actual part of a total schedule taken from work done at a government installation during the week of February 26.

In this case, only five machine groups are involved, but the savings to be accomplished by the method is 121 hours for a week. If all the work and machines were included, the expected savings would be much higher.

The underlined figures show where the work was actually assigned and the X's indicate the mathematical programming solution, arrived at as outlined earlier.

THE PROBLEM OF SEASONAL SALES

For many firms, sales may fluctuate quite widely at various times in the year, creating problems of production and storage bottlenecks, idle manpower with high turnover and training costs.

When the seasonal pattern is not extreme, or can be treated as two separate phases, the problem can be handled by double application of the principles of inventory management.

For example, if sales are constantly high during the summer and low during the winter, such as in the farm implement industry, the economic lot formulas can be applied twice: to forecasted winter usage; and to forecasted summer usage. Thus, such a firm will have two sets of order quantities and two sets of reorder points.

AN ACTUAL SCHEDULE OF MANUFACTURING

(Similar examples are typically found in automatics, chucking equipment, Forge Presses, and other operations. Many installations of MP to these areas are presently in use.)

Type Mach. / Order	4 Spindle Acme	1 Spindle Cleveland	B & S OG	6 Spindle Acme	B & S 2G
1	158	355X			
2				58	43X
3				22	21X
4				91X	
5	36			37X	
6	28	53X		29	
7				39X	56
8	36X	65			
9			26X	34	
10		210		39X	
11			20X	18	
12				11	9X
13				14X	20
14		14X			
15			11X	18	
16		39X		26	
17			25X	22	
18			33X		
19				19X	23
20		174X		128	
21					39X
22	19				18X
23		38X		39	
24		33X			
25			5X		
26		18X		20	
27		14X		15	
28					6X
29				77	80X
30				98X	112
31				15	16X
Actual Time Required	36	839	170	394	251
Time Used By MP For Same Work	36	738	170	387	238
Savings: 121 Hours					

Even under the principal of double application, bottlenecks may develop which will complicate the issue beyond reasonable human ability to solve in the most economical fashion.

Fortunately, for complicated problems of this type, Mathematical Programming can be readily applied without undue technical training.

Through the use of Mathematical Programming, it is possible to solve the seasonal problem taking into account all the interrelating factors of: storage capacity, production capacity, labor costs, the guaranteed annual wage, over time costs and storage costs. Taken in their entirety, such an accumulation of factors would pose a prohibitive barrier against the solution by mental gymnastics.

The use of Mathematical Programming permits the problem to be of any magnitude and more important, it guarantees a solution which is best for the conditions imposed.

Hence, Mathematical Programming offers a savings in overall plant operation that far exceeds any of the procedures previously discussed. It is my firm belief that this area is one of the most fruitful areas for the application of Mathematical Programming, exceeding the savings that these techniques have accomplished in such diverse fields as production scheduling, profit analysis and distribution applications presently in use.

There is good reason for such a statement: First of all, the problem is a typical recurring one in many companies, and second, it represents an area in which management has heretofore tried piecemeal solutions, usually based on expediency.

An illustration will suffice to demonstrate the problem: A company makes a large number of products in which labor represents one third of the cost -- material representing the other two thirds. The sales forecast has been made for the coming year. This forecast is next reduced to total man hours required to produce the forecast. Hence, all figures are given in terms of man hours.

The forecast is shown below in Figure 12:

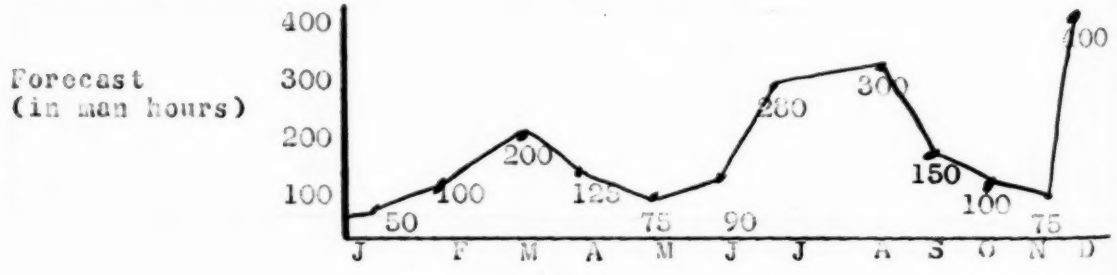

Figure 12

The labor rate is $2.00 per hour and overtime is $3.00 per hour. The material cost (per man hour) is $6.00. The firm also has a policy (similar to the G.A.W.) in which each employee receives $1.00 for every hour he is layed off. The carrying charge on inventory has been determined to be 24% per year, or 2% a month (actually a non-linear carrying charge can be included without complication). The operating capacity of the plant (in man hours) is 170 per month. In actual practice, the productive rate should be computed for each month, because the number of days varies from month to month. The overtime production rate per month is 30. Finally, the firm is on the Lifo system such that they wish to return to the same inventory each January 1. On January present, the inventory is 100.

Once the data has been gathered, it is formulated into a table called a matrix to be solved by Mathematical Programming. The table is shown below with the best solution indicated by the circled figures.

The figures in the column entitled "Forecast" are the amounts to be produced to meet the forecast. Since 100 units are on hand in January, and production in January will be used at some later period, starting in February.

The -3.16 in the small square under column "J" is the cost of producing the product in January for use in February. Since the item is stored one month, the carrying charge is 2% of $6.00 or $.16. The figures in the J° column are the costs for overtime production, plus storage.

The solution indicated shows that no overtime is required and that a maximum storage time of two months will meet the requirements.

Other solutions can be obtained simply from this one: First it is possible to determine whether it is cheaper to work overtime and reduce personnel; or second, it is possible to evaluate an increase in personnel versus storage costs.

The table as set up can be made to include a number of other factors such as training costs and non-linear carrying charges.

Because the table includes all pertinent data normally associated with such a problem, the evaluation obtained will quite naturally provide better answers than could otherwise be obtained.

The problem as stated has been considerably simplified. Warehouse restrictions can be added and other products with different seasonal patterns included.

SEASONAL PRODUCTION TABLE

MONTH	FORE-CAST	J	Jo	F	Fo	M	Mo	A	Ao	M	Mo	J	Jo	J	Jo	A	Ao	S	So	O	Oo	N	No	D	Do
F	50	-8.16 (50)	-9.18	-8.00	-9.16																				
M	200	-8.32 (25)	-9.36	-8.16 (170)	-9.18	-8.00 (5)	-9.00																		
A	125	-8.48	-9.54	-8.32	-9.36	-8.16 (125)	-9.18	-8.00	-9.00																
M	75	-8.64	-9.72	-8.48	-9.54	-8.32 (40)	-9.36	-8.16 (35)	-9.18	-8.00	-9.00														
J	90	-8.80	-9.90	-8.64	-9.72	-8.48	-9.54	-8.32 (90)	-9.36	-8.16	-9.18	-8.00	-9.00												
J	280	-8.96	-10.08	-8.80	-9.90	-8.64	-9.72	-8.48 (45)	-9.54	-8.32 (170)	-9.36	-8.16 (65)	-9.18	-8.00	-9.00										
A	300	-9.12	-10.26	-8.96	-10.08	-8.80	-9.90	-8.64	-9.72	-8.48	-9.54	-8.32 (105)	-9.36	-8.16 (170)	-9.18	-8.00 (25)	-9.00								
S	150	-9.28	-10.44	-9.12	-10.26	-8.96	-10.08	-8.80	-9.90	-8.64	-9.72	-8.48	-9.54	-8.32	-9.36	-8.16 (145)	-9.18	-8.00 (5)	-9.00						
O	100	-9.44	-10.62	-9.28	-10.44	-9.12	-10.26	-8.96	-10.08	-8.80	-9.90	-8.64	-9.72	-8.48	-9.54	-8.32	-9.36	-8.16 (100)	-9.18	-8.00	-9.00				
N	75	-9.60	-10.80	-9.44	-10.62	-9.28	-10.44	-9.12	-10.26	-8.96	-10.08	-8.80	-9.90	-8.64	-9.72	-8.48	-9.54	-8.32 (65)	-9.36	-8.16 (10)	-9.18	-8.00	-9.00		
D	400	-9.76	-10.98	-9.60	-10.80	-9.44	-10.62	-9.28	-10.44	-9.12	-10.26	-8.96	-10.08	-8.80	-9.90	-8.64	-9.72	-8.48	-9.54	-8.32 (160)	-9.36	-8.16 (170)	-9.18	-8.00 (10)	-9.00
To Re-turn to Stock	100	-9.92	-11.16	-9.76	-10.98	-9.60	-11.80	-9.44	-10.62	-9.28	-10.44	-9.12	-10.26	-8.96	-10.08	-8.80	-9.90	-8.64	-9.72	-8.48	-9.54	-8.32	-9.36	-8.16 (100)	-9.18
Idle Pay	455	-1 (95)	0 (30)	-1	0 (30)	-1	0 (30)	-1	0 (30)	-1	0 (30)	-1	0 (30)	-1	0 (30)	-1	0 (30)	-1	0 (30)	-1	0 (30)	-1	0 (30)	-1	0 (30)
	2400	170	30	170	30	170	30	170	30	170	30	170	30	170	30	170	30	170	30	170	30	170	30	170	30

PLANT CAPACITY BY MONTH
AT STRAIGHT & OVER TIME

Once the problem has been formulated properly, it can be solved by a checker-board system of Mathematical Programming, or Vogel's Approximation Method.

THE PROBLEM OF DEFINITION

It is a relatively simple venture to define Methods Improvement, and at the same time impart an insight into its usefulness. For example, we can discuss the meaning of work-place layout, drop delivery and the like and quickly dispell most chances for misunderstanding.

Not so with Mathematical Programming. For one thing, even after you have attended a few conferences and read a few papers on the topic, most of you will still want to look further before you really know MP. This is because a few examples are inadequate to convey the scope of the techniques. One or two examples, unfortunately do not lead the way to other areas of application. In fact, the problem of training personnel in Mathematical Programming is not so much the techniques, but to widen the horizon of applications by covering a large number of examples. In this way the conferee can begin to relate the case to his own wide range of problems.

As a parting shot, however, I would like to pass on to you a definition which we have found to be most useful. It is in terms of the conditions that make up a MP problem:

1. There must be a goal. Such as highest profit, least cost, or the like. Every problem in industry is concerned with amelioration.

2. There must be a number of choices or different ways of taking action. In the machine allocation problem, we had a choice between machines. The seasonal problem presented choices between storage, production, overtime and idle time.

3. There must be a set of restrictions. These are the things we <u>cannot exceed</u>. We should not, for example, exceed the speed limit. We are restricted by our plant capacity, company policy, and our sales forecasts.

4. There must be a set of requirements. These are the things we <u>must do</u>. We have to drive on the streets and not the sidewalks. We have to produce the products we have promised our customers.

5. There must be a rate of efficiency between the many choices. In the machine example, one machine is more

efficient than another. One process costs more than another. One shipping route is cheaper than another.

These are the conditions which are common to all MP problems. They do not necessarily guarantee that a problem that fills these requirements is an MP problem, but if the problem can be solved by MP, it will be of this nature.

If you try these out on a few problems that are bothering you and they fit, there is a good chance that MP can help you.

LABOR-MANAGEMENT AND THE PROBLEMS
AND PROMISE OF TOMORROW

by
Walter P. Reuther

Mr. Chairman, fellow Americans, and friends:

I appreciate very much the opportunity of participating in this Convention.

I might say that my first impression of your organization was not a good one. I came here very promptly, figuring that engineers would be very precise about everything they did. I arrived at exactly one minute to seven, and after I hung around in the outer lobby there, I was finally told to get in line.

I got in line with all the distinguished people who grace the speaker's table, and they said, "We are going to march in, because when we get in there, we will all be in our proper places."

Now, we marched in a very straight line, but when we got in here the fellow who should have been on that end (indicating) was on that end (indicating).

And, of course, you see, this has disillusioned me. Because I came here believing that engineering was an exact science.

Now I have a better understanding of why our fellows in the UAW in the shop look upon some of the standards you work out with some question marks in their minds.

The other thing that impressed me about your meeting is the relative youth of your membership. I asked myself the question: Could it be that industrial engineers, like industrial arbitrators, are expendable and don't last long in business?

The Chairman said I came to Detroit in 1927. That, historically, is true. And when he recited that, it reminded me of the fact that when I first came to Detroit I was just a young boy, and I joined the Y in Detroit because I had a great deal more energy than I knew what to do with. So I used to go over to the gym there every day, or every other day, and burn up some of the energy. When I joined the Y, they gave me, as they gave to all other applicants, a very comprehensive questionnaire. They asked me many questions such as what church I belonged to, and other things. The last question was very important. It said:

"What is your ambition in life?"

Well, I pondered that question, because I hadn't as yet made up my mind. And because I couldn't make a choice between two very tempting possibilities, I wrote both of them down. The first I wrote down was "to be a labor leader," and the second "a chicken farmer." Do you know there have been many, many times in Detroit when the highest management people said to me, "You would have made a wonderful chicken farmer."

Now, I have not come here with a prepared speech. I made a few notes very hurriedly this afternoon between meetings. I won't be able to read them.

But I want to think out loud with you about some of the problems that we face -- management, labor, free people generally.

The subject that they gave me was "Labor-Management and the Problems and Promise of Tomorrow," and perhaps I will touch on that a little as I go along.

First of all, I think we need to understand that we live in perhaps the most challenging period of human history. We have before us a future that is pregnant not only with the possibilities of war and destruction, but with a promise of human betterment and human happiness unprecedented in any other period.

Literally, we stand on the rim of hell. With the H-bomb and guided missiles, mankind has the capacity to destroy human civilization. Yet the same science and the same technology that give us the know-how to make the H-bomb and the guided missile provides mankind with the tools and economic abundance. The great challenge is not: "Do we know how to make a bomb?" or, "Do we know how to create economic abundance?". The great challenge is: "Will we be able to organize a world society in which man will use the constructive application of these new-found powers and reflect them in terms of the basic human and democratic values that we as a free people cherish?". That, really, is the great challenge.

The challenge bears upon all of us. This is not something that the diplomats or the men of power, in a governmental sense, have a monopoly on. Free labor and free management, engineers, educators, religious leaders, people in every walk of life must jointly search for the answers to these problems of the future.

This is really the first time in the history of human civilization when mankind has the tool with which to master his physical environment. This is the first time that we know how to feed and clothe and house the human family, to satisfy mankind's economic and material needs. Having found the answer to mankind's economic needs, we can begin to devote greater time and energy and resources to facilitating man's growth as a social being, as a cultural being, as a spiritual being. This really is the beginning of human civilization in its higher aspirations. This is the first time that mankind as a family can rise above the struggle to survive as an economic animal, and can begin to grown in terms of these other basic spiritual values.

I have been saying that the possibilities of human betterment are as unlimited as the creative genius of the free human spirit. There are no horizons we can not penetrate. There are no tasks we can not master, providing we find a way to apply this great ingenuity, this great creative power, to the pursuit of positive values.

For centuries and centuries the struggle -- and the history of the world is filled with this struggle -- was a struggle of one against the other, of group against group, and nation against nation, the have-nots struggling to get their share from the haves. A nation enjoyed a high standard of living because it built their its standards upon the exploitation of less fortunate people. The economic tools were not sufficiently efficient or productive to enable man to meet the needs of the whole human family.

Then we were struggling to divide up economic scarcity. Then one fellow had enough to eat only because someone else was hungry. That period of human history has come to an end. We now have the glorious opportunity to cooperate in the creating and in sharing of economic abundance, and in distributing economic abundance in a world where poverty is no longer beyond mankind's control.

This brings new problems, and, of course, new opportunities.

There is a great revolution sweeping the world. We are a long ways from it, and perhaps that is why we don't understand it. It is a revolution that grows out of this basic change in the world -- the revolution of the economics of abundance. Neither Adam Smith nor Karl Marx could have understood this, because they interpreted the world in the period of economic scarcity and they could not have realized the possibilities of the economics of abundance.

This revolution that sweeps the world is the most powerful force now at work. It is the thing that moves hundreds and hundreds of millions of people in Africa and Asia and Latin America. In their wretched lives, as they struggled to keep body and soul together -- they have come to realize that they need no longer live in hunger and privation. Perhaps they have not grasped the full meaning of the concept of abundance. Their limited understanding has kindled the stars in their eyes. They finally have come to understand that their ancient poverty, the social injustice that bore down upon them and their ancestors for centuries, is not ordained by divine providence; that social justice is something within their grasp and within their control. They know that somehow they can begin to organize their economic resources and they can begin to take positive steps to abolish poverty and hunger, ignorance and disease, and the other ancient enemies that have plagued them throughout the years.

This is the revolution in the world.

The Communists didn't create this revolution. They are riding on its naked back, for they have perfected the techniques of forging human poverty into

political power. Because we are the strongest and the wealthiest of the free nations of the world, we especially need to realize that people all over the world are going to find an answer to poverty; that the have-not nations are going to get their share of the good things of life.

The question is: Are they going to solve their economic problems within the framework of a democratic society, or are they, in their sheer desperation to get the wrinkles out of their empty bellies, going to grab the promise the Communists offer -- the promise of economic security at the price of political and spiritual enslavement?

We must understand that these people are powerfully motivated by poverty. It is hard for you and me to understand what poverty really is. Here is what poverty means in India, for example:

In India, the average income three years ago was $50 a year. By heroic effort they have raised it to $56. But there are still 70 million people in India who last year had an income of less than $20 for the whole year.

Now, intellectually you cannot understand that. You can only understand it emotionally. And you must see poverty in its ugly naked form to understand it in terms of its human tragedy.

I saw it in India. I saw little three, four, and five year old boys and girls hacking away with little hand hoes in a parched potato patch, looking for tiny potatoes no bigger than a pea. This was the fourth time they had dug these potatoes. The first time they went through, they gave better than 90 per cent of the crop to the people who owned the land. The second time they went through, they gave 80 per cent of the crop, or some figures like that, to the people who owned the land. The third time they went through -- the same potato crop -- they got a little bigger percentage. And the fourth time they went through, they got to keep all the potatoes themselves, but there weren't many to be found. Here these little children were dropping potatoes no bigger than a pea in the basket with the sun 107 degrees in the shade; they were hacking away. Mothers with babies strapped to their backs were digging with their other children. And we of America, with our great resources and power, are dyeing our surplus potatoes so that they will be burned and not used for human consumption.

We have a billion four hundred million bushels of grain in "surplus". Unless we understand that with this great wealth goes a corresponding moral obligation, we get into trouble. Our wealth becomes a liability unless we have a high sense of social and moral responsibility.

However, with an appropriate sense of moral and social responsibility, our wealth can be a great asset in this struggle to preserve freedom and peace in the world. We need to understand that your freedom and my freedom will not be made secure in America; it will be made secure in the world in which these forces are at work. It will be made secure in a world where millions

of people seek an answer to these ugly, nasty human problems. What we need to do is to help people to help themselves so that they can gain more bread, and at the same time, also gain more freedom; so that they can get food in their empty bellies without the need of putting their soul in chains.

This is the basic challenge.

The struggle in the world, as we have said in the labor movement many, many times, is not a struggle for geography. It is essentially a struggle for men's minds and their hearts and their loyalties. That struggle could not be won with guns. We need to be strong on the military front in order to meet the threat of Soviet or Communist aggression, no matter where it may raise its ugly head. But we need always to realize that military power is but the negative aspects of a dynamic foreign policy; that it is the holding action which buys us the time to take positive action on the economic and social fronts in the struggle against poverty and hunger, ignorance and disease, and great social injustice, for these are the ingredients out of which the Communists forge their power.

The American labor movement is a part of the great family of free labor movement in the world. There are 56 million free organized workers who stand today as the great bulwark against the forces of Communism. We are the front line troops, not because we are better than other people but because we understand -- and translate our knowledge into positive action -- that the struggle in the world to preserve peace and the struggle to preserve human freedom are inseparably tied together with the struggle for social justice. You cannot preserve peace or freedom in a world in which hundreds of millions of people are denied their measure of economic and social justice. You can look around the world tonight, and where you find a country with a strong free labor movement, with a labor movement with the will and the courage and the vision and the sense of social and moral responsibility to struggle to get for the great mass of people in that country a measure of economic and social justice, you will find in that country Communism is weak and unimportant both economically and politically.

When you find a country -- and France is a good example -- where there is no strong free labor movement, where the Communists control the labor movement, for they do not solve problems but exploit them, you find there that the Communists build their power out of the great injustices.

The free labor movement believes that what we need to do is to recognize that because we are the strongest of the free nations of the world, we have a corresponding obligation, and we need to provide leadership, not only political, military and economic but also moral leadership.

I have been saying that if we had the good sense -- and I am going to so testify before the Foreign Relations Committee of the United States Senate tomorrow morning -- that if we had the good sense to use our great food abundance with courage and imagination, with a sense of responsibility, in terms of our moral obligations, to use it in a program to fight poverty

and hunger in the world, this food surplus would give us a moral power with great impact in the world than all the power of all the H-bombs we will ever build.

The tragedy of America is that we have lost contact with the realities of the world situation. We have put all of our eggs in the military basket. Because of our failure to grasp the social dynamics of this changing world, we are trading reliable friends in Asia for very doubtful military allies.

These things are important because we are playing this one for keeps. There will be no return match because we either win the peace or all is lost. The tragedy is that we have a banker mentality about waging the peace. The House of Representatives voted -- with one dissenting vote -- last week to appropriate $33 billinn for guns. It is the old business, billions and billions and billions for war. I saw it during the last war, where I served on all kinds of Commissions, the War Manpower Commission, the War Production Board. I watched the Congress, the Appropriations Committee. When the General said, "Give us billions for bombs," and the Admiral said, "Give us billions for battleships," the Appropriations Committee didn't say, "We can't afford these things." They opened up a big 24-inch valve and they appropriate billions and billions and billions. And yet when you say, "Let's fight this thing on a positive basis in terms of the needs and the hopes and the aspirations of people in peace time," they never open the 24-inch pipe line. They get out the congressional "eye dropper" and they give you a couple of drops.

You see, this is not realistic.

What we need to do is to get realistic.

We have a great opportunity in America to really lead. I believe that the American economy is, in truth, freedom's greatest material asset. There is nothing like it in the world. Yet, based upon our resources, compared to what we could do, we are failing miserably.

On the home front we have some of the answers. I believe that collective bargaining, labor-management relations, are a decisive factor with respect to the future of the American economy.

I believe that collective bargaining provides us with the economic and social tools to begin to try to equate our great economic progress to human progress.

When I was in India, I was asked on several occasions: How much influence do American unions have?" They said to me: "What about your union? How much influence does the UAW, the Auto Workers, have?"

I said, "Well, it is difficult, really, to define those intangibles. But I might put it this way: that the Auto Workers Union has enough influence to make the General Motors Corporation say, 'Yes,' when it would like to say 'No.' That is how much influence we have."

There are other unions that have influence.

We try to use this influence, not as a narrow economic pressure group, but as a force that recognizes that in a free society no one can really solve his problems except as he works with other men and women of good will in finding answers to the problems of the whole community.

Now, our dilemma in America is the fact that there is a developing moral and cultural lag between the tremendous progress we make in the physical sciences and our failure to make comparable progress in the human and social sciences. We know a great deal more about how to work with machines and materials than we know how to work with people. Working with people has always been much more difficult than working with machines because a ton of steel, 12-gauge, out of the U. S. Steel Mill in Pittsburgh, is quite uniform, but every human being, thank God, is different. And this raises problems.

We need to recognize our basic problem is that while we have raised scientific and technical and production know-how to a high level of achievement, we need to develop a comparable human and social and moral know-why to match our know-how. Economic effort is not an end. It is a means to an end. The end is the enrichment and the fulfillment of human life.

Sometimes we get our equations somewhat confused, and our vision gets out of focus. I believe that in the contest in the world between the forces of freedom and the forces of tyranny, between the forces of democracy and the forces of Communism, the world is going to judge America, and we need to judge ourselves, by how well we meet human need, not by our economic wealth or our productive power or how many new Chevvies we can make in a year. These are not the real measurements of the worth of a civilization. The true measurements of the greatness of a civilization are not how wealthy is that civilization in terms of material values, but by what sense of moral responsibility does that society reflect material wealth in human values. How do we translate technical progress into human progress, into human happiness, into human dignity? These are the standards. It is in this field we need to be working. The lag between technical progress in the physical sciences and the failure to begin to match the know-how with know-why in the human and the social sciences is going to confront the American people and the American economy with basic problems in the years ahead, and we shall be in trouble unless we begin to get these things in their proper balance.

In that connection, I would like to touch very briefly upon some essential principles that I think labor and management need to keep in mind when they sit at the bargaining table.

I call these the common denominators of democratic survival between free labor and free management.

First, labor and management need to understand, and we all need to understand, that human freedom is an indivisible value; that human freedom can only be enjoyed in its social context.

Robinson Crusoe didn't know what human freedom was when he lived with his goats. You can only have human freedom in association with your fellow man. Labor and management need to understand that you can't have free management without free labor, and you can't have free labor without free management. Neither can be free unless we learn to work together to preserve a free society in a free world.

Secondly, I think we need to understand that freedom in terms of the basic values that we as a free people cherish, free labor and free management have a great deal more in common than they have in conflict.

Thirdly, we need always to understand that in a free society there is no legislative substitute for the voluntary discharge of social and moral responsibility.

The tragedy of America in the field of collective bargaining is that the very people who make the most noise against Government intervention in the whole field of economics and social action are the very people least willing to carry their responsibility on a voluntary basis. It is their failure to voluntarily meet the responsibilities that creates the vacuum which Government compulsion must fill.

You take the National Association of Manufacturers. They are far to the right of Louis XIV.

And if they could do it, they would repeal the twentieth century.

It is their kind of social irresponsibility that stands in the way of making the kind of progress in the human and social sciences which is essential to achieve this balance with the progress in the physical sciences.

You just read American history! The loudest voicesthat condemn Government action, Government intervention, are always the same voices that refuse to meet the challenge on a voluntary basis.

Fourthly, collective bargaining decisions must be based upon economic facts, and not upon economic power.

How often do you think collective bargaining takes place unrelated to the facts? I sit across the table with the highest priced management representatives in this country, and I participate in the highest level of collective bargaining takes place in the absence of the essential economic facts that ought to go into the collective bargaining decisions. Too often economic power becomes a substitute for economic facts, because management is unwilling to place all the facts on the table.

There are these little private economic Iron Curtains behind which they hide the essential facts, of the relationships of wages, prices and profits. These are not matters that are private, because they bear upon public decisions that affect all the people. Yet this is the way collective bargaining is conducted in America.

Only as economic facts determine collective bargaining decisions can we effectively work at raising collective bargaining above the level of a struggle between competing economic pressure groups. Collective bargaining can perform its basic economic and social functions in a free society only as the decisions of the bargaining table reflect the needs and the welfare of the whole of society. Neither labor nor management can, in truth, make progress except as they make progress with the total community and the total nation.

The sixth point or principle -- and this is one that I could write several volumes about and give it a lot of spicy details in terms of specific situations and personalities, for this is the problem that cries for attention: Collective bargaining in a free society must be based upon a single set of standards of economics and morality. Too often we find two standards -- one set of economic standards for the management, one set for the workers; one standard of morality for the management and a different standard for the workers.

Take the pension question! I could tell you, how, long ago, I went to the bargaining table about pensions and how they said to me: "Why don't you tell the workers to save for a rainy day? Then they won't need pensions."

When the automobile workers were averaging less than $1.50 per hour, I had a corporation executive who told me that at the time he was making over $300 per hour if you evened out his annual income from bonuses and salary on a 50 week basis, giving him two weeks off for vacation. On a 40 hour week basis, making over $300 per hour, and yet he said to me, "Tell the dollar and a half per hour workers to save their money for a rainy day, and then they won't need a pension." Yet with his $300 an hour, his corporation already had provided for a $25,000 pension for when he was too old to work but too young to die -- because they didn't think he could save for a rainy day on a measly $300 per hour.

Now, these are double standards. And they won't work.

I don't begrudge one General Motors executive, or any other of these highly paid executives, one penny they get. I get my reward in another way. I say that the way you measure whether your life was spent worthwhile is really, in my opinion, not by the size of your bank account but by how you have worked with other prople in trying to advance the cause of human justice and human dignity. That is my reward. They have theirs. I have mine. So I don't begrudge them their money. I have had many attractive offers from these fellows. I prefer to be where I am. I think the Auto Workers pay me too much, as a matter of fact.

I ask you this question. I have raised this at many, many management meetings. This isn't something I say behind their backs. I tell them: I believe in the free enterprise system. As a matter of fact, I am more pro-free enterprise than most of the membership of the NAM because if they go in their own stupid selfish way, they will destroy free enterprise. I want to try to make it work. The only way to make it work is to make it reflect the needs of the great mass of the people. It has got to find a way to raise the standards of living of the many and not just the standards of luxury of a few.

So I tell them: "Now, I believe in free enterprise. I believe that individual initiative and incentive is a powerful constructive economic motivation. And I am for it." But I say, "Tell me what kind of moral and mental gymnastics you fellows go through to arrive at the conclusion that if a worker is getting $4,000 a year, and he struggles with his fellow worker to try to get $5,000, that that is economically dangerous and morally wrong, while if a corporation executive is getting $400,000 and he is trying to get $500,000, that is economically sound, that is morally right, that is the highest expression of the American way?"

And yet that is exactly what happens under this double standard of economics and morality. I say this will never work. We need a single standard.

The seventh point is that the only way you can have more is out of the economics of abundance; that labor and management need to realize that as they apply their respective skills in the industrial process, as they use these new tools that automation and atomic energy are going to give us down the road, they must find a way to live with, to manage, and to share abundance. This is the only way our economy will work. The eighth point, principally, is that the future of the American economy is not going to be found in your slide rules. It is going to be achieved in terms of a dynamic balance between greater productive power balanced by greater purchasing power, always on a higher and higher economic plateau, always achieving that dynamic balance because a mass production economy cannot survive without mass purchasing power.

I went through the Ford Engine plant in Cleveland where they knock out those Ford engine blocks fully machined in less than fifteen minutes without a human hand touching them. It's quite a plant. You could hardly find the workers scattered among those acres of automatic machines. The plant management contrasted the size of the work force with the size of the work force which used to turn out engine blocks in the Rouge plant. There was a time when the Ford Motor Company made a simple Model T engine block in twenty-four hours. This was hailed as a tremendous technological achievement. Now the rough casting comes out a finished block in 14.6 minutes.

The management said to me gleefully, "How are you going to collect dues from these machines?"

And I said, "That is not what is bothering me. What is bothering me is 'How are you going to sell them Ford cars?'".

That is the problem. You know, you cannot set up a parallel line automated to make plastic consumers. Thank God that still can be done only the good old-fashioned way.

Now, you may think that this is a problem only in my imagination. I tell you that right now the auto industry is already technologically able of turning out cars faster than the American economy can turn out consumers.

We are in trouble. Nobody can deny that. The industry knows it. They don't want to talk about it, but the facts are apparent. There are more than 130,000 people in Detroit on the streets. Mr. Curtis said yesterday that he had to revise his projections for '56 down 22 per cent from 1955. Last week we made 37 per cent less cars than we did in a comparable period in '55. Spring and the robins have come late to Detroit, and the spring pick-up has not come at all.

These are facts, not fancy. These are facts in the world in which we are under pressure from Communism.

They have automation. And don't you get the idea they don't know how to use it, because they do.

I say that we need to find an answer. There are more than 900,000 cars in inventory. If there is a pick-up in sales, it won't reflect itself in higher employment and more jobs, because the inventory is so tremendous they can meet any improvement in sales out of the more than 900,000 cars in inventories. We are in trouble, because of the imbalance between wages and prices and profit, between production and purchasing power. You don't have to take a Ph.D. degree in higher economics in Yale or Harvard to know that. It is simple, simple A, B, C's.

This is our problem. I say we need to work at it.

What happens with unemployment? It breeds unemployment. That is why we fought for the GAW; and I tell you, yes, sir, they are going to find all kinds of roadblocks to other answers to this problem, but they are only wasting their time, because we are going to find an answer to this. You know, in '49 we started after pensions. They ran their full page ads. They said this was going to threaten the very stability of the free enterprise system. Chrysler, where we had a 108-day strike said that the funded pension plan would dry up available capital, would stymie industry, and free enterprise would shrivel up. When we got to the GAW fight in 1955, they ran full page ads bragging about how wonderful the pension program was.

Some day, when we have the GAW the way it ought to be, they will be bragging about that, and we will be fighting for a shorter work week.

That is how you make human progress. That is how it is made. There are no other ways to do it.

Now, why did we fight for GAW? We said, and we were right, that the guaranteed annual wage is more than a matter of economic justice to the worker; it is a matter of economic necessity. When you get more than 130,000 automobile workers in Detroit on the street, when there are thousand in Flint and Kenosha and South Bend and Toledo and New Jersey and all over the country out of work, it means that these workers have their income curtailed, and that as consumers, their purchasing is cut back. Things that they would buy which other workers would make, are not purchases, and then those other workers get laid off. Unemployment breeds more unemployment. Then you begin to get a compounding of the negative unemployment factors, negative economic factors. Unemployment makes more unemployment which makes more, and you get in trouble, whereas if you got a temporary dislocation and the workers had their income shored up with a guaranteed annual wage system, then you would not have a compounding of the negative economic factors. This is just simple basic economics. Yet when you talk about these things, you would think that we were threatening the very foundation of the future of our great economic system.

We did very well in '55. But don't ever forget that we did it under great pressure and great stress because of the insane competitive struggle in the automotive industry.

You know, they can say one thing publicly, but they talk to me privately. They can't tell us how they do it. We know how they schedule production. They would have you believe that this is all a reflection of the market. There is a very fine mechanism here, and they watch it microscopically. That is a lot of poppycock, and they know it, and we know it.

General Motors sets the pace. If it is an insane pace, they all get in the race. That is the way it is done. That is why we have more than 900,000 cars in inventory. It didn't just happen. It is a result of this kind of competitive insanity.

Now, if this insanity could be isolated from people, it would be unfortunate, but it wouldn't be tragic or serious, to families to people.

Do you know how we sustained automobile sales for the last two years? By having millions of Americans spend wages and salaries they hadn't earned yet. They were spending future income. And consumer credit for new automobiles alone went up to a rate of 14½ billion dollars. That is where it is today. If you think that is a healthy thing, you are just ignoring the economic facts of life.

Now, this imbalance developed because the wages and the prices and the profits got out of adjustment.

Last year manufacturing corporations in America made a profit of 35 per cent greater than in 1954. American farmers lost over a billion dollars in income. Millions of American families living in depressed areas have experienced unemployment as chronic and a kind of a way of life.

Now, this balance between the wage, price, profit equation is not an arbitrary thing. General Motors, in all their wisdom, can't sit up in high places and make that arbitrary decision. The UAW can't make that arbitrary decision. These are not fixed relationships. These are relationships between these three essential factors in our economic equation, which must reflect the needs of our society.

If we are in a period where there is pressure of purchasing power upon the availability of good, then the stress must be shifted to expanding the capital goods industry, to creating the tools that will create more consumer goods. Having created those more productive tools, this greater industrial capacity, we must then shift the stress to the purchasing power part of our equation so that we can expand the market to absorb the greater production made possible by the expansion and the more efficient plant capacity.

This is the thing that we have to keep in balance. It is a very delicate balance, but it can be done. It must be done because that is the key to this dynamic relationship between productive power and purchasing power, in which we will achieve higher and higher material prosperity on ever higher economic plateaus.

Now, you take the question of automation. Take the question of atomic energy. I served on the Civilian Panel created by the Joint Congressional Committee on Atomic Energy. We spent a year studying this. And I tell you now that we are not facing up to the problems or the possibilities of atomic energy in America. We, also, are not facing up to either the problem, the challenge or the promise, of automation.

Everybody knows what they are doing, but nobody knows the total social impact that automation will bring -- nobody. We need to begin to work on this problem. Unfortunately there has been much more heat than there has been light on the social and economic impact of automation on our society. It will have a greater impact upon the white collar worker than it will upon the industrial worker, because you can automate office routine where you don't change models much easier that you can automate a manufacturing plant, where you change models and tools. We are not projecting this problem into the future.

We need to be thinking about the location of plants. Is this just a private decision, where a company can make a private decision and turn a city into a ghost town? I think not. I think that there are new responsibilities that need reflecting upon in these basic private economic decisions.

There is the whole question of the timing and of the flow of automation into the main production stream. There is the retraining of workers, the kind of job, the kind of training program, the kind of transition machinery we must plan ahead for. We are not doing that.

I have proposed, not because I want a lot of machinery set up, that some sort of a technical clearing house be worked out by labor and management and consumer groups working with the Government, so that there would be one technical clearing house where we would assemble all of the information and the developments, both in the field of atomic energy and its social and economic impacts and automation and concerning the new technology.

General Motors knows pretty well what they are doing. And I suppose in a general way they know what the automotive industry is doing. And so does Ford. And so does Chrysler. And General Electric and Westinghouse know about their industry, and other industries know about their special concerns.

But no one has a total look at the total problem. We need to pull it together because you cannot get the kind of intelligent approach to this unless somewhere someone has a look at the total impact.

I think we need to understand that the social responsibility of ownership is of a changing character. If you own a simple production tool in which one man applies his energy and his skill in the use of that tool, the ownership of that tool carries with it very limited social responsibilities, but when you own an automated factory, your social responsibility increases in direct proportion to the productive capacity of those tools and to their potential possibilities of creating economic dislocation.

That is just a simple rule: if you own a simple tool, you can't do much harm if you use it unwisely, but if you own a great factory or hundreds of great factories, and whole communities and hundreds of thousand of people depend upon your economic decisions, then your decisions must reflect a much higher degree of social responsibility than the decisions of the persons who own the simple tool, that cannot create dislocation.

This is not a matter of philosophy. This is a matter of practical economics because a free society could not survive unless it meets these basic problems.

As a matter of fact, the Communists think we can't meet them. That is why they believe that ultimately they will prevail. I think they are wrong. I believe that free men can find the answers to these problems, but we cannot find them by any narrow, doctrinaire approach.

What we need to do is to find our place in America on the high ground between the social jungle of a kind of laissez faire capitalism, with its calloused indifference to human values, and the swamps of a ruthless regimented economy in which an all-powerful State enslaves the human spirit. Some where on the high ground between those two extremes we must stake out our kind of philogophy, our kind of economics, our kind of tomorrow -- not based upon dogmas, but based upon a kind of pragmatic idealism that relates our developing technology to these basic human problems.

I have a belief that this can be done.

You know, this question of ownership is a greatly misunderstood matter. Ownership doesn't change anything as far as the wealth that the tools of production can create. That is a matter not of ownership but of the level of your technology and your economic resources as you apply those technologies to those resources. Ownership only fixes responsibility. It doesn't do anything else. And therefore to private ownership, an institution I support, must go this increasing responsibility.

Another thing I think we need to do in America: We need to learn to sell our ideas and our ideals in the world as effectively as we have learned to sell our cars and our cosmetics.

We do well on these. I was in North Africa last summer, and I made a speech in the public square of Tunis. When the meeting was over, they said "Do you want a cool drink?" We went around the corner, and put our nickel in and got a bottle of coke. In North Africa! We know how to sell our cokes and our cars and our cosmetics. And we had better learn to sell our ideals and our ideas because that is the great contest in the world, between the free world and the world of communist activity.

Now, I personally have unlimited faith in America. I have unlimited faith in the capacity of free men. Along with a lot of our people, we fought our way out of a social jungle. And don't kid me about whether it was that or not. I know because I worked back in those days, when you were just a nameless, faceless, clock card number. Then you had no rights, no status. You were to be used and dumped on the street whenever they got ready.

I have seen the whole thing develop. I think there are great possibilities in America. Labor and management are learning to grow up together. It is a mutual process because in truth, labor cannot grow much faster than management and management not much faster than labor, in our total group relationships.

This experience has given me great, great encouragement. I have unlimited faith in the capacity of free men in our great country.

But there are a couple of things which bother me. Yesterday they dedicated the General Motors Tech Center, a $175 million model engineering research center. I was supposed to go there, but I got involved in something and didn't make it; I hope to make a trip through it very shortly. No question about it, there is a symbol of the great technical progress we have made.

But I am worried about a problem that I would like to raise with you, because you might help with it. We are losing the technological lead that we have had, and which has been the basis for our great leadership in the world. The Russians are picking up very fast. They are picking up because America has not maintained its educational system equal to the challenge.

Millions of American school children are being robbed of their rightful educational opportunity.

Oh, we talked about that. We have many noble phrases and pious platitudes about our children being our most priceless national asset. Then we put them in antiquated over-crowded school buildings with underpaid teachers. That is tragic. We are robbing these children of their rightful educational opportunity. We believe, in the labor movement, that every child, regardless of race or creed or color, all made in the image of God, has a right to the highest kind of educational opportunity so that every child can grow intellectually and spiritually and culturally, not limited by an overcrowded schoolroom, but limited only by the individual capacity of that child to grow.

This educational lapse is the tragic part of American life.

What bothers me in terms of the struggle in the world is that we are falling behind in the educational process, at the high school level and at the university level.

On the atomic energy panel, when we talked about atomic energy research, the Atomic Energy Commission's own program -- found the AEC can't get enough engineers and scientists to carry on even their program. Industry can't get them. They are stealing them from the Atomic Energy Commission. They are stealing them from the university faculties.

And every aspect of our program in the atomic energy field is being restricted and held back because of a shortage of trained engineers and scientific personnel.

Now, what is happening in Russia? Well, the best available information is that in 1920 the Russians had 41,000 graduate engineers. In 1955 they had 541,000. In 1952, we had in the United States 215,000 graduate engineers. Today we have roughly 500,000.

In 1955, the Soviets graduated from higher learning institutions 63,000 people in the engineering categories, and in 1955 we graduated 53,000 in the same categories.

Now, this is not just a quantitative difference.

I was told by a leading educator, the dean of one of the leading engineering schools in America, that the Russians are doing a superb qualitative job; that a four year engineering student in Russia has the academic equivalent of a master degree of five years in the United States. In 1953, the Russians graduated 29,000. In 1950, we graduated 52,000, and we dropped back to 23,000 in 1955.

On the over-all, in the field of engineering and science, they graduated 170,000 people in all of these categories, and we graduated 70,000 in 1955.

In the last five years, the number of qualified teachers in our secondary schools and our universities in the field of science and mathematics, dropped 53 per cent. This is where we get in trouble. If a young boy or girl can't get science and math in his high school, he just can't be available and qualified for engineering and science later on.

This frightens me. If the Russians continue to move ahead, it means, that they will be able to begin to harness the atom, the new technology. They will use that not only in terms of their own economy, not only for military power; they will use it to implement their new offensive, the new look, which has not fooled me, because I think they are still determined to dominate the world if they can. They will use this new power, that this growing army of technicians and scientists will give them, to advance their program of economic penetration.

Now, this is the world in which we live. This is the world in which all the values that we as a free people believe in are in jeopardy.

You and I, labor, management, free people generally, must look at these facts not as we would like them to be, but as they are. We must begin to plan realistically to realize the full potential of the economic abundance that we can produce if we apply our new technology to the fullest, so that we can raise our living standards, so that we can reflect technical progress into human progress, and so that we can help other people to help themselves in the struggle against poverty and hunger in the world. If we do that, I have unlimited faith that free management and free labor and free people can meet the challenge of tomorrow, and that they can realize the promise of a better day. Together with free people everywhere, we can move forward. We can shape our programs and our policies in the image of our faith and our hope, and not in the image of our hatred and our fears. Together we can build a better tomorrow, and we can fashion that better tomorrow in the image of peace and freedom and social justice and human brotherhood. Thank you. (applause)

THE RESEARCH PROGRAM OF THE AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS

Dr. Andrew S. Schultz, Jr.
Director of Research, A.I.I.E
Professor and Head, Department of
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I am honored to be here and I am very grateful to have the opportunity to talk to you on this subject, which is the Research Program of the American Institute of Industrial Engineers. My topic was selected for me by your program chairman and it is the sory of a topic that must be delivered to a captive audience. This in no way diminishes its importance or my sincerity of interest in it, but I am glad you are held here and don't have the freedom of movement that you would have if this were being covered in a technical session.

In his opening address on the topic of Industrial Engineering in Transition, Donald Malcolm made a number of good points. It is my purpose to elaborate on a few of them and some of his own phrases will be used.

He spoke of the explosive technological developments that are currently taking place in this most dynamic field of engineering. The fine program followed in these two days of technical sessions is illustrative both of the explosive technological situation as well as of the dynamic nature of our field of interest.

In the area of work measurement, we have many problems related to sampling, to applications of statistics, to the development of standard data systems, as well as automatic recording devices, which are definitely in the books for the future and which help to shape our research problem.

In the area of methods, plant engineering and design, the words "automation", and "feedback control" are illustrative of the developments which have been going on for years. Equally important here is the concern with some of the aspects of human engineering and with the development of much needed design parameters.

In the area of organization planning, the program includes papers on communication nets, information flow, and experiments pointed towards ultimately more objective factors for organization development.

In the area of production control you are hearing about new techniques which involve decision rules, the application of

linear programming to the problem, and the quantification of inventory procedures generally.

In addition you are hearing about new research which develops objective measures, about operations research, and of course, the fundamental statistical method which underlies all of our work.

The above series of examples illustrates the breadth of the problem as presented by the technical sessions. Another aspect of the research problem is equally well illustrated by a quick analysis of the disciplines represented among the speakers. If we leave off those who spoke at the meal sessions, we find that we have a chemist, a philosopher, four mathematicians, three physicists, two psychologists, a lawyer, two business administration people, and three mechanical engineers, three electrical enginers, and eight industrial engineers. In other words, industrial engineers are providing about a quarter of the program. There are no sociologists on the program, but they are working, and their research is going to have a direct and significant impact upon our work.

So we find that the research program for the A.I.I.E. must definitely be influenced by the breadth of disciplines which are making contributions to fundamentals upon which our work is based.

There are a number of other aspects of the situation which help to shape our research problem. We find, on the part of many people doing research important to us, considerable lack of knowledge of our areas of operation. This is generally associated with ignorance of the previous accomplishments of industrial engineers in attacking these areas.

On the other hand, we find on the part of many industrial engineers a lack of familiarity with the new developments. And, of course, there are frequent occasions where a young engineer who possesses some knowledge of these new ideas finds it impossible to sell his superiors on their use.

Nevertheless, there exists in industry and in other areas an increasing demand for industrial engineering functions. This demand logically stems from the need for better plant and production controls resulting from increasing unit labor costs and increasing volumes. One aspect of this trend was pointed up by Mr. Reuther last night. In connection with automation an error or mistake is usually much more expensive than it otherwise would be. This emphasizes the need for more and better industrial engineering.

A heartening development found in many industrial firms is the broadly increasing responsibility delegated to their industrial

engineering departments. However, this all emphasizes the point that it is a lot later than we may think as far as the development of this organization is concerned. A new era and a younger management is beginning to demand more and more. And it can be foreseen that this management will find itself in a position in which it must have more and more from us.

Mr. Reuther last night made a point of Soviet competition in the production field. We have all read in recent months statements by various individuals who presume to be authorities on production matters that the Soviet group is improving on our production abilities, and up until now we have flattered ourselves that we were without comparison the leaders in this area of endeavor.

The problem that we face here is to develop in the situation as it has been outlined a research program that will meet the needs of industrial engineering now and in the future. It can be stated that these needs include among others these two important ones. The first is the requirements of industrial engineering education comprising understanding, cooperation, and responsibility of industry. Involved here is also the need for a feedback from industry to education which involves the pressure to advance. The educational problem is a serious one and an indication of a successful solution will exist when majority of those engineers practicing industrial engineering are found to have taken the degree in the field.

The second important need referred to is that of the industrial engineer in industry. This involves the necessity to identify clearly the areas involved and to associate new developments in these areas with our practice.

Don Malcolm said it very well yesterday when he said we need a faster, more efficient introduction of change. We must provide an opportunity, both for specialized development for the individual in one or more of these areas, and also an opportunity to become broadly familiar with the new conceptions. And in these two needs, at any rate, there is an identity of interests between those in industry and those in education who are represented here today.

In an article prepared for your journal* the speaker pointed out the need for translation of new developments resulting from research in the physical and social sciences into techniques and application. This is an important part of any professional development and must be considered with the other points previously mentioned.

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* Nov.-Dec. 1955 - Journal of Industrial Engineering

It would seem that these needs would shape objectives of a research program in this form:

Provide, first, a broad structure meeting our immediate needs, and those foreseeable ones. Currently, it should be capable of providing maximum aid and encouragement to research in the area of industrial engineering through, first, the provision of a medium of interchange of information - which we lack; secondly, through the provision of a formal organization to assist in achieving understanding and recognition and encouragement of good research. And that is an educational problem, in part.

Also, it should aid in definition of areas or problems which need study, and, finally, in a broader dissemination of the results achieved in such research.

From a longer range point of view this structure should provide a basis for the organization of specialized divisions within the American Institute of Industrial Engineers when such action appears advisable. Within a few years this Institute will become of such a size that similar divisional development to that of such organizations as the A.S.M.E., A.I.E.E., I.R.E., and others may be essential.

A third ultimate need is, of course, a basis for research accomplishment as a result of direct action by the institute.

The proposed program to do all this looks large, but it is not too large in view of predictable growth of the A.I.I.E.

It involves, first, a Research Council, which should be composed of representatives of both education and other areas, industry as well as Government, to provide advice and counsel, a two-way exchange of information.

The actual work, of course, what there is to be done, is to be done by committees. We cannot assume that the Research Committees individually, as committees, are going to do research. We find nothing in life or other technical associations to match this.

We have at present a series of seven or eight staff research committees. The proposal is to take our field, make a slight shifting of the subject matter, and set up ten research committees, which have, as their responsibilities, a number of things, including, among others, keeping up to date with their own specialized area; provision of assistance in programming in such meetings as this; the encouragement of research, and the appraisal of new developments in the area, and resources in the area, and the taking of action to call these things, these needs, these developments, and these accomplishments, to the attention of those who should know about them.

In addition to this, there is called for a series of research committees which are not primarily concerned with the subject matter, but directly concerned with encouragement of research. There are five of these in parallel with the functional committees to the organization, and briefly they are:

First, a Prize Committee. Those of you who are chemists are familiar with the Chemical Society activities in that area. We should have a means of segregating, pointing out, and distinguishing, outstanding master theses, outstanding doctor's theses, and good work done in both industry and academic life through some types of prizes. It is a difficult problem because it involves selecting and receiving and reviewing many papers. It is not easy. It also involves raising the moneys to do this. That will be easier.

Second, there is the Fellowship Encouragement Committee. Many industrial firms are offering graduate fellowships in engineering and science. Many of these fellowships are not in the field of industrial engineering. Our committee should be able to ensure that more of them embrace the area of our interest.

The third committee is a Research Information Committee, to provide a medium of information exchange as to work in the area. Maintenance of records of research under way, these abstracts, and liaison with research agencies of other societies is involved.

Next, there is a Research Support Committee, which can aid in directing into the area types of support that are needed, both on the part of Government Sponsorship and Foundation work.

Finally, there is a Research Publication Committee, to continue with the monograph series and publish those reports which are too lengthy for the Journal, too good to be allowed to die, and too esoteric for a commercial publisher to handle. We are going to have more of such every year.

Now, I would like to take this opportunity of thanking the many of you who have aided me, answered my letters, and made suggestions in the development of a program of this sort. I would like to reiterate my own belief that our success as a professional organization will in no small measure depend upon our success in achieving status in this area. We shall be distinguished from the purely technical associations, such as bankers, embalmers, and undertakers, chiefly in one area, by the success of a program of this sort.

I think it is important to us. It is very heartening to see a program such as John Nevros and the others have put together. It is heartening to see what is going on in the many universities today and in a relatively few number of industries, and I am sure, with your cooperation, we shall be successful in achieving these objectiv

Thank You.

MANAGEMENT'S VIEWPOINT OF IE'S ROLE

John L. Schwab
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It is a pleasure to address once again a National Conference of the American Institute of Industrial Engineers, and I would like to begin by complimenting your organization and especially those responsible for these fine arrangements for the excellent work they have done. I especially wish to commend the program committee for the impressive array of subjects and speakers. The AIIE is becoming more and more successful in effectively presenting the technical phases of the industrial engineering profession, rather than attempting to blanket the entire field of management. You are to be congratulated on the fine service you are rendering.

Usually, and unfortunately, most conferences are like a Hereford steer--a point here, a point there, and a lot of bull in between. Generalized conferences usually fall into this category, but one such as you arranged today has a lot more points than the remaining commodity. Unfortunately in some respects my topic--Management's Viewpoint of the Industrial Engineer's Role--does not lend itself to pin-pointing specifics as do some of the more technical subjects. But it does provide an opportunity for a real soul searching. Let's begin. First, it is obvious I have two choices of the direction to which I can direct my remarks.

1. To only the recognized good things about our profession which all of us like to hear.

2. To the truth, via a factual analysis of the good and the bad alike.

What you would like to hear can contribute little if anything to our profession, so let's forget it. But, even though we be engineers rather than poets, I am sure we all appreciate the wisdom of Bobby Burns' quotation, "Would some power the gift would give us, To see ourselves as others see us." Such an understanding not only is helpful--it is vitally necessary if we are to be successful as a profession or as individuals, for equally important with what we are is what others think we are. We may be the most competent, capable, and honest group in all society, with the greatest contribution to make to our fellow men--but if those with whom we live and work believe otherwise and continue to believe otherwise, we have nothing to contribute to society and have nothing for ourselves but our personal satisfaction in being right. Hence, our existence as a profession is meaningless.

PURPOSE OF THE INDUSTRIAL ENGINEER

Before describing management's viewpoint of our role in the business world, it is important that we ourselves thoroughly understand the basic purpose for which we exist as a profession. Books have been written to define it, but they can be rather simply condensed to one statement: Namely, to provide management with decision making facts, information, and data to serve as a basis for sound administrative judgments and decisions. Thus, as engineers, we are expected to provide measurements, both subjective and objective in nature, to those executives responsible for the policies, decisions, and actions of the organization.

As a corollary to this basic purpose it might be stated that we are obliged to serve as junior counterparts of executive management, for after combining the how, why, and wherefore of the basic information with maturity and experience, we can quickly develop to a level of accomplishment which merits the authority and responsibility necessary to make decisions.

The conditions which make the climate so favorable for this are peculiar to this profession alone, for it is only in the industrial engineering field that an engineer is required to deal with the three all-inclusive functions which make up the management of an enterprise. As an industrial engineer you must deal with physical materials necessary for the development of new and effective methods, tools, processes, and procedures, as one of your prime responsibilities. You must understand costs, hence prices, because your time data, plant layouts, cost center setups, and the like are the very basis of every cost accounting procedure. Finally, and perhaps most importantly, you are dealing with human beings--selling them, explaining to them, gaining their cooperation--in one of the most intangible arts and/or sciences of all-- the measurement of human effort and the establishment of a fair day's work.

Top management has recognized this since the creation of the industrial engineering profession many years ago. But top management tends to be impatient with, and, quite frankly, disappointed in our actions. The reasons--we look too often (or at least give that impression to others) to our tools of industrial engineering as cure-alls for management's problems and we apparently give the impression to top management that the only answer to every new problem of management is the creation of a new tool.

Take a look at our program for this conference. As I said before, it is an excellent conference, but look at the four and eight syllable words used to define many of our techniques which will have a direct effect and bearing on operators as well as our top management. I would conservatively estimate that no more than 2%

to 3% of the industrial engineers here today could concisely and understandably explain the majority of the topics to a top executive. I am quite certain that the percentage of top management men who could do likewise would be no greater. Hence, many tend to believe that we are merely a group of mathematical mechanics and human computers and some of us, with our bright eyes and eager-beaver approach, do little to ease that suspicion. Thus, we have an unfortunate combination--difficult to understand techniques and over-enthusiastic salesmanship. It is no wonder others are frightened at the worst, and doubt our practicability at the least.

To change these misconceptions, we must ourselves truly evaluate our profession and the tools we use in order to get down to "basic" thinking. The true purpose of these tools, may I repeat, is merely to provide clearly understood and acceptable points of information which will serve as a basis for agreement and/or stepping stones to progress. But, these tools by themselves do nothing. I am sure none of us expect a mathematical equation to carry a gunny sack, nor do we believe that a predetermined motion time system by itself can convince an operator or an engineer who is trying to save face during a piece rate dispute. We must always remember that these devices are merely tools which compliment our judgment. They have been created to overcome certain weaknesses which we poor mortals unfortunately have.

Such reasoning must be applied to every industrial engineering tool, whether it be MTM, Operations Research, Linear Programming, or any other catchily phrased and important-sounding technique. Consider the example of a pencil as a tool. I am sure that all engineers would agree that a common lead pencil is one of the most perfect tools designed by man. It is inexpensive, hence readily available to all who wish to enjoy its benefits. It serves its purpose better than any other tool at its price as proven by the fact that its design has remained unchanged for decades as a writing instrument. It it easy to handle, and it even has a device which few tools have--a corrective factor for human error in the form of an eraser. So here I have in my hand one of the finest tools devised by man. And yet, as I lay this perfect tool on paper and command this tool, as it lies there inanimate, to write something as beneficial to man as the Ten Commandments or as revolting as a kidnapper's note to a bereaved parent, the pencil remains lying there, inanimate, accomplishing neither good nor evil. Thus it shall remain until it is taken into the hand of a human being. Then, and not until then, does it become an instrument of accomplishment.

Management, as I mentioned earlier, looks to the industrial engineer as its replacement corps. As such, they are looking for generalization, not overspecialization; for adaptability, not singleness of purpose. Our tools, therefore, must be understood and used by

understanding humans, for in the final analysis it is the people themselves who accomplish the task, not the tool.

The types of tools we use, the vast quantity of them, and their complexity are the things which cause top management to look askance at our profession. For example, I have a power lawn mower at my home, complete with every conceivable kind of attachment. It came equipped with an excellent kit of tools containing 15 assorted types of screw drivers, each for special purpose screws which hold the blades, wheels, tires, and other related parts of the machine. Occasionally, as I am mowing the back end of my lawn, the mower breaks down and I am faced with making some decisions. I must walk about 600 feet to the cellar, select the right screw driver, and return. So, manfully I trudge forward, make a selection from this group, and return--praying that I have the right blade so that I won't be required to make another trip. Every time this happens, I long for a good old-fashioned 8-bladed Scout knife with which I could turn practically any screw on the mower.

Managerial jacknives are what managements are looking for in the industrial engineer. Every top management executive recognizes that he has on his staff men who are more capable of handling a specific phase of the business operation than he. But, what they need in addition are men who can appreciate the fundamental human importance of the managerial job--men who are more appreciative of the fundamental philosophy and policies involved in operating a business than they are in the use of the routine measuring devices which create a true specialist. They are looking, as Dr. Gomberg pointed out in regard to Mr. Wilson, for those who can be pragmatic in their approach to basic problems of running a business.

AN EVALUATION OF INDUSTRIAL ENGINEERING TOOLS

It is not so easy for us who are so well acquainted with our tools of industrial engineering and their use to realize that others might not be so fully informed. Therefore, I should mention the necessity for us to evaluate each tool of industrial engineering in order to determine any shortcomings which top management might unwittingly or unknowingly ascribe to them. An evaluation is a simple and effective means for systematically uncovering errors or misunderstandings. As a result, it clearly indicates the actions which we should take to correct the causes of these difficulties.

First and most important we must impress on management that we fully understand that these industrial engineering techniques are really no more than measurement devices, or expressions of data which attempt to put on paper a base point from which our minds can first agree and then make a decision as to what is right, what is wrong, or what we intend to do. This is typical of any measuring device, whether it be one of a tangible nature, such as a micrometer,

a yardstick, a speedometer, or whether it be a less tangible method of measuring, such as a union contract or a series of company rules. But whether it be tangible or intangible, this measurement must meet two specifications. It must be understandable to everybody effected by it, and accepted by all if it is to be effective. Then, and not until then, can it serve as a basis of agreement and a tool for mutual progress. If not understood and accepted, it is inevitable that the measurement will become a source of controversy, disagreement, and failure.

It seems to me, therefore, that as industrial engineers our primary job is to develop these tools, procedures, and devices to a maximum of understandability and acceptability.

SPECIFICATIONS FOR A MEASUREMENT

Generally speaking, a measurement can be readily understood and accepted only if it meets the following four specifications.

1. Easy to understand
2. Quick to apply
3. Consistent
4. Reproducable

These four criteria should serve as the basis for evaluating any and all of our methods, for compliance to them is a true measure for their potential success or failure.

First, we must question the ease of understandability. Our natural reaction is to say "Yes", for it is easy for our trained minds to agree since they are affected by a natural bias which any man has toward a subject or device which he thoroughly understands or has created.

The specification of understandability, however, deals not with you, its creator or expert practitioner. More importantly it is concerned with its understandability by every man or woman who is affected by our industrial engineering procedures. How well <u>they</u> understand it, what <u>they</u> truly think of it--both are of prime importance to general acceptance and use of the technique. We must recognize that it is use and use alone, which makes our procedures useful and contributory to progress.

It is obvious that the more tangible a device, the more understandable and acceptable it is to all. For man accepts that which he can recognize with his senses of sight, taste, feel, and touch, more readily than any device or tool which is affected by semantics

and opinion. The limitations of language place greater dependence on mutual faith than on mutual understanding, hence are more subject to disagreement by conflicting personal interests. Consider my tie as an example. Note the color and figure carefully and then if you agree with the following statement, please raise your hand.

"My tie is predominantly brown in color and the figures are a series of small triangles in a contrasting color."

As you can see from the raised hands we have complete agreement. This is as it should be, since all of us know what the color brown is (with the exception of those who have the misfortune of being colorblind), and all of us who have had the advantage of a grammar school education understand and comprehend a triangle.

Since both of these statements apply to something seeable, we have a basis for agreement. Hence the advantage of tangibility.

Now, let's make another test using the same subject. Will all those who agree with this statement please raise their hand?

"My tie is pretty."

May I humbly request the audience not to comply with my request, for my tie is a gift from my wife and I am sure that no one would wish to criticize her taste. However, both you and I know that there is a great doubt that the audience could reach unanimous agreement, for the adjective "pretty" is intangible since it is a matter of individual taste and opinion, rather than a matter of universal understanding and acceptance.

The second point specified the necessity for speed in application. The tools had to be quick to apply--not to save installation costs by management, but in order to provide any potential benefits impartially and economically to all. I'm certain you will agree that there is no greater source of dis-harmony in industry than that which stems from the granting of advantages and/or benefits to one group of our people while denying others the same equal opportunity. The majority of industrial relations disputes over wages are created by this condition. One corporation which recently suffered a long strike can lay the blame for a portion of their difficulty to attempts to apply work measurement without wage benefits to indirect employees while direct labor employees were permitted to enjoy incentive pay. I hasten to add that I am <u>not</u> justifying either management's or labor's claim in this dispute. I am merely pointing out the basic human reason which lead to the dispute between management and labor was inequality of opportunity, which can also result from the use of time consuming, complex, difficult to understand, and costly to apply tools and procedures.

The third specification mentioned was consistency, since consistency is accuracy. Do our data always give us the same answer? Is the information supplied consistent or do the same figures give you different answers? This point must be emphasized, for when one talks about measurement, the terms consistency and accuracy are synonomous. If our tools and their application are consistent, we will not create a dangerous condition similar to that mentioned beforehand. For a consistent device properly applied will inevitably give everyone the same equal opportunity, hence, a better basis for understanding and acceptance.

The final point which must apply is in regard to the reproducibility of any of these tools of engineering. This last item is important if we are to gain the faith of others who wish to use any of these devices. I must at this point mention an item about which I wish to take some of the AIIE members to task. At your last convention I felt it necessary to comment on a book sponsored by the AIIE which criticized the basic approach of predetermined motion times and related work measuring systems in general and MTM in particular. I wish to once more repeat my comments, since I find they were not heeded three years ago. In addition, the necessary corrections were not made in the original text and I find that Dr. Gomberg has even included this data, complete with errors, in the most recent edition of his book "A Trade Union Analysis of Time Study."

First, a word about criticism itself. I believe it is absolutely necessary, for criticism is usually the result of many inquiring minds devoted to solving a mutual problem. Obviously, their findings are of major assistance, and the more minds engaged in studying a problem, the more quickly and effectively the solutions are found, purified, and improved. Hence, it is a most wonderful and necessary activity.

I am now in the position of criticizing a critic and his criticism. The book "Functions and Basis of Time Standards" by Dr. Harold Davidson as published by the society was replete with statements and interpretations completely erroneous and at odds with any findings and concepts of those of us who developed and published MTM and, I am certain, of those who developed Work Factor, BMT, and the like. Now, I can understand how overenthusiastic critics could misunderstand and misconstrue words which were written in the text, since the limitations of language are well known to all of us. If such were the case I would not emphasize such criticism. However, the errors of simple arithmetic contained in these books are so ridiculous as to be almost beyond comprehension. As just one example, may I point out the tables for the comparison of Methods-Time Measurement, Work Factor, and Professor Holmes's data, on Pages 156-157 (Table #6) of Dr. Davidson's work, and on Pages 227-228 (Table #7) of Dr. Gomberg's book "A Trade Union

Analysis of Time Study." To make this comparison, the authors were required to convert the MTM time values (which are in hourly units) to decimal minutes. The conversion procedure required two steps--the selection of the proper time value for a given motion from the MTM data card, and then the conversion process of multiplying the hourly value by .0006. Out of 54 chances, 33 errors in selection and/or multiplication were made. I might especially call to your attention the fact that in seven multiplications, the decimal point was misplaced. Furthermore, it is bad enough that the original errors were made and published, but to repeat the same mistake by including the table in another book produced by another published is so ridiculous that I am sure it will do little to enhance our reputations either as critics or as engineers.

I hope I do not impress you as being hyper-critical and especially do not wish to give the impression that I am resorting to ridicule. I never ridicule any man, or his work, for ridicule is, after all, merely a last resort of someone completely uninformed and desperate because of lack of knowledge of a subject which he fears. When he cannot argue it on a basis of fact, ridicule is the only answer. I promise I will never lay myself open to such a charge.

There are many things about which we can be critical when considering these tools, but now let's erect a defense of our ideas to top management. First, may I say that many of us are inclined to be hasty in our judgments. Take, for example, the criticisms which have been levelled at industrial engineers for their so-called huckstering techniques. All of us have been accused of over-emphasizing our work at the least, and in making outright falsehoods at the worst. It is somewhat difficult to defend against statements of this kind since they contain a modicum of truth. Yet, in the final analysis, we must realize that all of these actions which we now decry are a necessary part of the birth and growth of a product, procedure, or profession.

All of us remember the exaggerated statements and claims first made for Chlorophyl, anti-histamines, and the like. While many of the original claims made for these substances could not in many cases be fulfilled, it is a fact that they have been and will continue to be valuable products which contribute in many ways to the betterment of our health. Undoubtedly the value of the wide acclaim and usage created by the so-called huckstering out-weighed any harm which might have resulted, for usage alone provided the final answers to their value. It has always been so, and will continue to be so.

A second point which we must consider is the criticism uttered by so-called "practical" people who state that we attempt to measure too accurately and that our measuring devices are too refined.

In answer, we must emphatically state that we can never be too refined in our measurements, for progress itself must be gauged by charting the development of preciseness in measurement. As an example, compare the present and past degrees of refinement of linear measurement with our present and past engineering developments. It is well for us to remember that the inch which we now so accurately measure with electronic devices, platinum bars, electrical wave lengths, and the like, was at one time defined as the length of three barley corns taken from the middle of the ear and laid end to end. And likewise, in 16th Century Germany the "rute" or "rod" was defined as the total length of the left feet of the first sixteen men who emerged from church one Sunday morning and were lined up heel-to-toe.

More than ever industrial engineering, like every other engineering profession, must constantly redetermine the bases of measurement to develop methods to reduce the chance of error, for it is only by increasing our preciseness, consistency, and accuracy that we can advance scientifically.

In this respect I will always remember the past ten years. During that time, when MTM (in which I have a deep personal interest as co-developer and co-author) was first introduced, criticisms, well-founded and otherwise, were constantly thrown at me both publicly and privately. Of all, the criticism most commonly voiced was in regard to the "ridiculous minuteness" to which the time values had been established and applied. And yet over that same period, thousands of MTM practitioners throughout the world have come to realize that the practicality of application of these minute pre-determined motion times is a well recognized fact, and that they can be applied with equal accuracy, consistency, and with far greater speed than can any other industrial engineering technique for establishing time standards. Their usage has proven this true for they have been found to apply equally well to operations as simple as tying a weaver's knot and to those as long and involved as the establishment of maintenance and construction time standards for the heaviest industries.

Ten years for the development of this or any science is a wink in eternity. Yet look at the progress which we in industrial engineering have made. We should be proud, for we can point out to management a fact which few of them realize, namely that in terms of elapsed years, the progress of industrial engineering as a profession and true science has been far more rapid than an equal level of progress in the fields of electrical, mechanical, or civil engineering.

Considering the field of work measurement alone, as an example, I can promise that you can expect far greater refinements in MTM

at least within the next two years, and I can tell you with certainty that the pre-determined motion time data card which will be understood and accepted ten years from today will be the size of this personal calling card which I hold in my hand. This may indicate how few classifications of motions and their corresponding time values this science will require. This is no idle statement for, in theory, we have already developed MTM to that degree. You may ask why would such refinement and minuteness be necessary when the existing data tables meet every practical need of work measurement. The answer is obvious. Existing motion time values as yet are still merely combinations of the original Gilbreth Basic Elements which we have not yet been able to isolate because of the limitations of our present measuring devices. To attempt truly fundamental and basic research with combinations of motions is like trying to do chemical research using compounds rather than elements. The elemental structure, in fact the nuclear structure, of motion times must be theorized, established, and proven. Then, and not until then, can we delve into the aspects of human behavior, human accomplishment, and human reaction to the depth so necessary for the advancement of our way of living.

While the present data are adequate for the measurement of work for incentive payment and other commonly used activities of management, only a small part of the real contribution which the industrial engineer's measurements of human effort can make are along these lines. Currently we are working on new measurements of nerve reaction time using MTM as a basis for the study. We are performing similar studies to determine, if possible, subconscious mental activities and their relation to fatigue. Again, MTM serves as a basic tool. Other similar activities involve the study of the effect of heat on productivity and fatigue, the effect of effort alone on productivity, and the accumulative effects of mental and physical fatigue on heart conditions. These are but a few of the deeply personal activities to which time measurements are now being applied and I have no doubt that during the next decade our studies will uncover more and more information which will indicate even more strongly the effect of our work measurement on other fields of humanics such as psychiatry, medicine, psychology, physiology, and the like.

Management must be informed--perhaps a better word would be "sold"--on the true effects our contributions can have for the betterment for mankind in general and industry in particular. We must broaden the outlook of our value to society in order to fulfill the niche which management has been holding open for us, but does not yet believe we have filled. So, we must not merely await acceptance, we must create a change in our own thinking and actions to merit it.

One thing which will not change is perhaps the most important part of any profession--namely, the basic philosophy around which it is built. This philosophy must be believed and conformed to if we are to be truly successful. This is what management expects of us, and adherence to such a belief will be the real factor in the success or failure of our profession. The philosophy of the industrial engineering profession is neither original nor unique. However, it truly represents the reason for the existence of our profession in logical sequence. I propose the following as a real philosophy for industrial engineers.

1. Every worthwhile business is established to fulfill an ideal. Its basic purpose is to contribute both to society and to those who finance, administer, and operate it. A business so conceived is created to progress, not to fail.

2. Progress can only be made by combining the efforts of those who create, administer, and operate the business. These efforts must be directed toward this common purpose if progress is to continue.

3. Faith is the basis for progress, for mutual faith between individual and groups of men assures common use of their abilities toward progress. But faith as it exists in men's minds can be destroyed by the conflict between instinct and reason and progress is then retarded.

4. Understanding is the power given us to comprehend. As such, it restores and bulwarks faith.

5. Understanding is created through the effective and objective presentation and acceptance of facts; facts impartially determined through searching analysis and a quest for truth.

6. Understanding through facts is therefore our aim and our goal, for understanding, alone, provides the solution to any or all management problems.

This is our philosophy, our aim, and our goal. This is what we must believe if we are to fulfill the demands of our profession and comply with the purpose expressed earlier in my talk. This is what management believes the industrial engineer's role to be.

Let's act it well.

PERCEPTION AND ANTHROPOMETRICS

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Man as a Perceiver

Man is many things. What he is depends on how you look at him. Perhaps to the biologist, he's protoplasm, to the chemist, elements, to the engineer, a servomechanism. The human engineer looks at man in still different ways. There are two main characteristics of man that concern the human engineer: man is a perceiver and secondly, man is an occupier of space.

Man can and does get to know what goes on around him by using his senses. Most scientists are content to deal with five senses, namely, vision, hearing, touch, smell and taste. Those who wish to get technical talk about the temperature sense and the sense of balance. And then there is the one apparently possessed by so few people: this is usually referred to as "horse sense."

All of our senses help us to live and do our work. The motion picture industry has been aware of the value of using the senses to communicate and entertain. First, there were the movies, then the talkies and now it has been suggested that, in conjunction with modern air conditioning, movie scenes of beautiful flowers and industrial processes might be more complete if the olfactory sense were used. The motion picture industry is striving gallantly to come up with an appropriate name -- so far the only suggestion, as you might guess, is the "smellies". However, for the purposes of controlling machines and communicating, very little use has been made of senses other than the visual and the auditory.

We may ask: Just what can man perceive visually and how does this relate to equipment design? First of all, normal men and women can see shapes, sizes, and colors. It may be well to point out what makes things "seeable." Sometimes, these are spoken of as the four fundamental factors in vision. They are: brightness, contrast, time and size. Most man-used equipment will have certain visual displays, that is, dials, scales, labels, and so on, which indicate how the equipment is operating and what should be done by the operator. If the man responsible for designing the equipment knows the optimum values of these four fundamentals, from the standpoint of the user, he will have about 90% of the visual display problem solved.

Table 1

Minimum Characteristics of Fundamental Factors
to Yield Adequate Seeing

Brightness	40 fl.
Contrast	5:1
Time	.1 seconds
Size	2 minutes of arc

In brief, (and very simple) terms the truly optimum values for these factors would be the maximum which can be efficiently obtained. That is, maximum brightness, maximum contrast, maximum time and maximum size. This will seldom be practical. In Table 1 are shown some more or less minimum values, or you may think of them as practical values, for these factors if seeing is to be considered satisfactory.

It may be helpful to state briefly what these mean or how they are measured. Brightness is measured photometrically and the footlambert is a unit of light reflected from an object and received at the eye. Contrast is measured in terms of ratio of brightness of adjacent parts of the object, e.g., to see a dark letter on a white page, the background of the page should be five times as bright as the letter. Time is simply in seconds. Size is related to distance so a meaningful unit is visual angle subtended by the object.

You will, of course, realize that there may be many modifying conditions which affect these optimum values, but in general terms, they will be correct. These factors, too, are interrelated. For example, if one value is very low, then it can be compensated for by having one or more of the others high. A low contrast object can be seen if it is large and if the observer has a long time to look at it.

Human visual perception has been rather thoroughly studied in the last fifty years so I can barely scratch the surface here in reporting some findings. A few sound principles used by the practicing human engineer can increase human efficiency in many industrial situations. If an operator must keep track of fast moving objects, the equipment designer should know something about eye movement. An eye movement of 20° arc takes about .06 seconds but a change of fixation from near to far distance consumes around .2 seconds. The unrestricted visual field without head

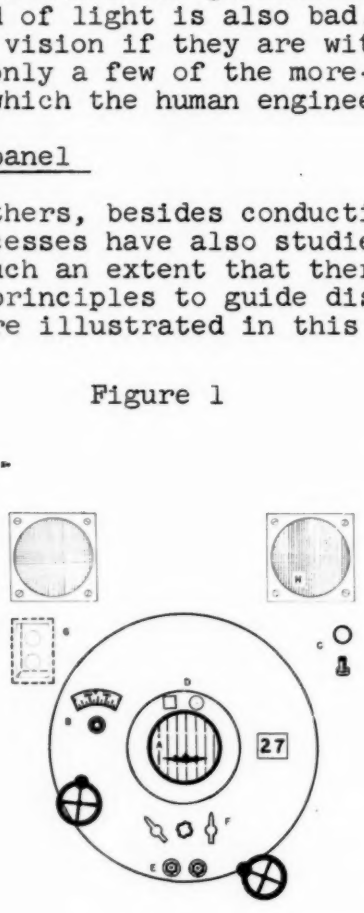
or eye movement is about 120° vertically and 160° horizontally, but the area of keen visual acuity is only about five degrees. Color coding is becoming increasingly important as a means of identifying controls. However, although the normal adult can discriminate an almost unlimited number of color differences when compared directly, when he views each separately, he can only identify 10 colors, viz., red, orange, yellow, yellow-green, green, blue-green, blue, violet, purple and bluish white. Also when he is viewing each separately, in a situation such as on an instrument panel, he can only identify 5 sizes of figures, 5 light brightnesses and 6 flicker rates.

Quick changes in the illumination under which an operator works may seriously affect his efficiency. When he goes from a bright to a dark area it takes him about 30 minutes to see well. Too much of the wrong kind of light is also bad. Glaring lights will seriously impair vision if they are within 60° of the line-of-sight. These are only a few of the more-or-less general principles of vision which the human engineer attempts to apply.

A typical instrument panel

Human engineers and others, besides conducting more or less basic studies on visual processes have also studied specific visual display problems to such an extent that there now exists a body of human engineering principles to guide display design. Some of these principles are illustrated in this imaginary instrument panel.

Figure 1



A Typical Instrument Panel

A--The most important visual display should be located at eye level and in the center of the visual field; while those indicators watched only occasionally should be farther from the center.

B--A control should be close to the indicator with which it is associated. Controls should be located so that the hands do not obscure indicators when adjustments are being made.

C--Pilot lights should be near the top-right hand part of a panel and associated switch should be thrown toward the light for turning ON.

D--Warning lights should be close to the ususl line-of-sight.

E--Connections such as phone jacks should be at the lower edge of the panel so that cords do not interfere with vision or control operation.

F--Controls which are of the same shape should be separated.

G--Infrequently used controls should be isolated by covering.

H--Speakers which may give different information should be separated and should be mounted above ear level.

In a way the console design characteristics about which I have been talking will appear to be only common sense. This is partly true but unless someone is responsible for the organization and application of these simple-sounding principles, the resulting console can be haphazard, inefficient, expensive to build and maintain, and the cause of mistakes which result in unsafe operation.

Practicing human engineers are more and more accepting this responsibility and having a unique appreciation of man's capabilities; they are insisting on designs suited to the man.

Glass bottle inspection, a case history.

To illustrate how human engineers undertake this responsibility in problems of a primarily visual nature, I will relate briefly a case history. This general problem is one with which I am sure, most industrial engineers are familiar. It concerns visual quality inspection in a factory. In this case the product was glass containers.

In spite of the advances in machine inspection, much industrial inspection is still done by human eye. Frequently, the inspection by eye is done as the object passes by on a conveyor belt so that the task is to see objects while they are in motion.

The problem posed by a large glass manufacturing company was to ascertain the feasibility of improving quality and/or quantity of glass bottle inspection.

Bottles are made by forming machines, are then cooled and move by conveyor belt past inspectors who look for the defects. These defects, although bearing many and diverse technical names, may be thought of as small cracks or bubbles in the glass. Actually there are 52 different defects which the inspectors must recognize. These carry such poetic names as: blister, stone, dope, and scabby bottom. Forming molds are carefully made and materials selected and mixed with great care so that most defects which occur are very small. In many cases, rejection of a bottle is based on a human decision that the defect exceeds an arbitrary "limit sample" -- the blister is too deep, the stone too large, the blemish too dark, and so on.

The task of finding these defects is rather enormous in terms of dollars and man-power. In this particular company the inspection job cost was several million dollars a year and accounted for some 25% of the company's personnel.

There are many psychological factors involved in this task of glass bottle inspection. These include problems in the field of vision, motor control, attitudes, psysiology and training. We shall restrict ourselves here to merely some of the visual aspects of glass bottle inspection.

Among the visual elements of the typical bottle inspection situation are the following:

1. the target (or defect) is moving;
2. usually the target is a low contrast mark or crack;
3. sometimes the target is seen as bright on dark and sometimes dark on bright;
4. besides being in linear motion, the target may be in vibratory motion;
5. the target is at variable distances;
6. the target is often near threshold size;
7. the target may be in different planes, i.e., on front surface or rear surface, inside or outside;
8. the target may be three-dimensional;
9. the illumination on this job may vary over a wide range (3-600 fc);

10. the target is surrounded by many extraneous light reflections or glare spots due to the inherent curved surfaces of bottles;

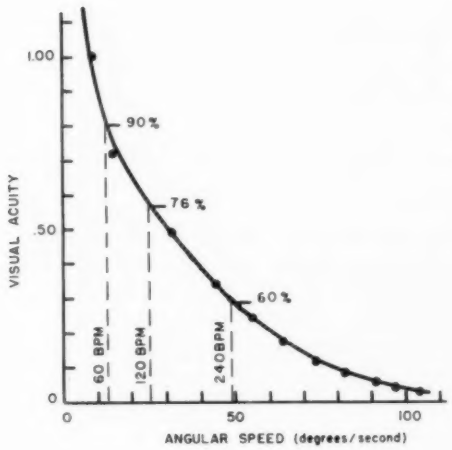
11. the form characteristics of the target are many and diverse.

The approach used by Applied Psychology consultants on this project consisted of the following: (1) orientation by means of several visits to the plants, (2) study of existing inspection records, (3) analytical review of published literature on inspection and visual performance; and (4) conferences with plant supervisory personnel.

Based on these activities, recommendations were made covering several pertinent matters; one of these was training. The use of training aids, and especially flash recognition training appeared advisable. Particular attention was given to the literature on motion aspects of visual inspection.

Company records and those of customers, ie., food packers, showed that the quality of inspection resulting from the existing set-up was remarkably good. Although no one would underestimate the seriousness of loose glass in a bottle or the possibility of bottle explosion due to thin or cracked glass, the very infrequent packing of defective bottles lead the consultants to believe that trying to improve quality of inspection was truly like looking for a needle in a haystack. This led to a revised aim, viz., maintaining quality and enhancing quantity.

Figure 2



Relation of Visual Acuity to Moving Bottle Inspection

A synthesis was made of the data on visual acuity for objects in motion and empirical evidence on inspection performance at various angular speeds of target movement. In this case target movement is best stated as the number of bottles per minute, abbreviated BPM, passing a point in front of the inspector. Such a synthesis is shown here in graphical form.

Here we have visual acuity in decimal terms on the ordinate (1.0 being "normal"), and angular speed of object motion on the abscissa.

The rate of bottle movement is shown here by the vertical dashed lines as 60 BPM, 120 BPM, and 240 BPM. In empirical tests using a typical inspection situation, 60 BPM yielded 90% inspection, while doubling BPM to 120 resulted in 70% inspection, a difference of 16% decrease in inspection. Due to the nature of the relation between speed of target movement and visual acuity as shown by the curved line, however, a further increase in BPM from 120 to 240, that is, again doubling rate, leads to the estimate that we would have a further decrease in inspection from 70% to 60%, a difference of 10%.

These percentage values are in terms of inspection of all of the bottles. As I have indicated earlier by means of careful construction of the forming molds, control of materials and of the forming process, only a small fraction of the bottles produced are actually defective.

When we take into consideration the small percentage of defective bottles produced we find that in terms of the percentage defective glassware passed by the inspector, this decrement in inspection when speeding up from 120 BPM to 240 BPM means an increase in defective bottles passed from 1.2% to 2.0%, a difference of only .8%.

In summary then, a 100% quantity increase would result in less than 1% increase in defective bottles actually approved by the inspector. With the increase in number of bottles per minute and assuming the necessity for increasing quality of inspection and taking into account the pay rate of inspectors, it would seem to be economically feasible to add another inspector on each line, thereby having another complete inspection. It is highly likely that this additional complete inspection would materially reduce the .8% decrease in inspection and possibly even wipe it out entirely.

Improvement of other aspects of the total inspection situation such as quantity and quality of lighting, personnel selection procedures, training, motivation, attention, etc., might more than make up for this decrease in quality of inspection and the economic return to the company would as a result of increased production be appreciable.

Other Senses

The things that I have said about vision as it relates to design of machines and processes can also be said of audition. Furthermore, as research progresses there will be similar human engineering principles with regard to the use of other senses. Especially promising is means of communicating and controlling through the tactual sense. The sense of touch is rather keen and is used a great deal in everyday living. Sometime pause and think of the many, many times in a day that you use the sense of touch in performing your work or adjusting to your immediate environment. You button your shirt, you steer a car, you eat your food, you brush your teeth, and scratch your ear. These are only a few of the acts you perform in so routine a fashion that you are hardly aware of them. Is it not possible that a body of principles derived from systematic research on the tactual sense might enable us to use it as a supplement to seeing or hearing, or even as a full-fledged communication technique?

Table 2

Reaction Times of Various Senses

Sense Organ	Reaction Time
Visual	.150 sec.
Auditory	.120 sec.
Tactual	.115 sec.

In our fast-moving age, literally and figuratively, we often wonder about time necessary to react. In this respect it is interesting to compare the reaction time to different sensory stimulations. Table 2 compares simple time to react for a visual, auditory and tactual stimulation.

These times are very brief because they are only the time necessary to remove a finger from a key when a sense is stimulated. For example, when a light flashes on the observer raises his finger. This is a simple task. A more complex reaction task might take up to several seconds to accomplish.

Also, these are <u>average</u> times, a few people will react much faster and some will react much slower. Although most communication is done by sight and hearing you will notice that if you want to get some action real fast, you can do so by utilizing the sense of touch.

What is the significance of this difference in reaction time? Here we have a difference of 35/1000 of a second between visual and tactual reaction times. Consider the situation of a 1,000 mph airplane -- it will cover about 1,500 feet per second. Therefore, in 35/1000 of a second it will cover 52 feet, not an appreciable amount in some respects but, if the pilot can be warned by a tactual signal, this small increment in time might be enough to avoid a head-on air collision.

Figure 3

FIG. 3. Exact sizes and shapes of the 25 stimulus items which met the criteria of 90% or better accuracy in Cond. 2 (solid figures, movement)

These Were "Readable" by a Finger Touch

I will cite an illustration of the feasibility of the sense of touch for use in equipment design. Figure 3 shows some letters which were "read" by touching them with the finger tip. These letters, numbers and geometric symbols were made into raised forms. They were identified with almost perfect accuracy even by untrained people with a mere touch of the finger tip. As you can see, there is some promise for the tactual sense as a channel of communication. I'll leave it to your imagination to surmise what would happen if the movie industry got hold of this!

We have reviewed briefly the human senses and have shown how, because man is a perceiver, information about the senses is important in designing equipment for human use.

Let us now take a look at another important aspect of man at work. This concerns man as an occupier of space.

Man as an Occupier of Space

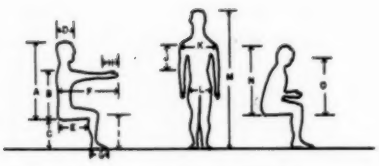
A major concern of industrial engineers for some time has been an efficiently arranged workplace. In recent years, human engineers have become increasingly interested in this problem, in some cases working jointly with industrial engineers. The task of providing man a suitable work arrangement has given considerable impetus to the study of the dimensions of the human body, called anthropometrics. These body dimensions are used to define the spatial characteristics of the workplace which must provide adequate room for the man. The workplace should not be so big that reaching for controls requires exhausting effort. Obviously, controls must not be beyond the reach of the operator. Also, if controls are too close to the operator they can be inadvertently actuated, perhaps with disasterous results.

Physical anthropologists have made extensive measurements of the human body on large groups of people, especially those in the military service. The measurements have been made in various technical ways and with specialized measuring equipment. We do not need to become involved here with the technical language used or with the refinements of anthropometry. Our objective is to point out some of the body dimensions which have primary practical importance in the design of equipment for human use.

Typical male body dimensions.

In Figure 4 are shown the average dimensions and the 5th and 95th percentile measurements. The extremely small 5% and the extremely large 5% of the men are not included here. It is assumed that for these people, special built equipment will be necessary.

Figure 4



	AVERAGE	90% BETWEEN			
A. erect sitting height	35.9	33.8—38.0	H. hand length	7.5	6.9— 8.0
B. trunk height	33.3	31.3—35.1	I. knee height	21.7	20.1—23.3
C. seat height	19.0	17.5—20.5	J. shoulder-elbow height	14.3	13.3—15.4
D. head length	7.6	7.3— 8.0	K. shoulder width	17.9	16.5—19.4
E. seat length	18.9	17.2—20.5	L. seat breadth	14.9	13.7—16.4
F. arm reach	34.6	31.2—37.3	M. standing height	69.1	63.1—75.1
G. foot length	10.5	9.9—11.2	N. normal sitting height	34.6	32.6—36.6
			O. normal sitting eye height	29.7	27.7—31.6

Anthropometric Measurements Related to Equipment Design

One point must be realized about these measurements, namely, they have been made on nude or lightly clothed subjects. The men were not wearing restrictive clothing and therefore, from a practical standpoint, these measurements will be in error for men wearing heavy clothing. For instance, standing height (M) may be increased by as much as 1.9" with the addition of heavy shoes or flying boots. Shoulder breadth (K) may be increased by an inch, while the arm reach may be decreased by as much as 4" due to the restrictions on arm mobility imposed by heavy pressurized clothing. Also, you will notice that there is an appreciable difference between measurements made in the rigid conditions of anthropometry and the normal conditions. This is apparent by comparing average values for line A (erect sitting height) and line N (normal sitting height) respectively 35.9" and 34.6". There is a difference of 1.3 inches. This difference is also represented by a lower eye level when the operator is in a normal, partially slumped, position.

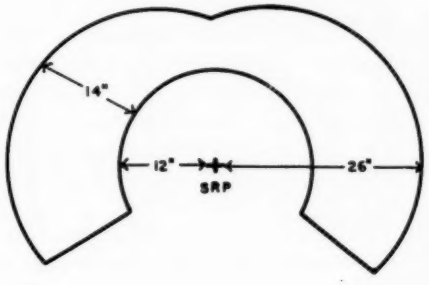
A Case of Restricting Equipment.

The clothing and equipment which the man wears or has attached to him are an integral part of him when designing for efficient human

performance. Let us consider the situation of an Air Force pilot in a modern high performance jet airplane. He is encased in a pressure suit and has attached to him various items of survival gear, such as a buoyancy, "Mae-West" type jacket. Forces of acceleration which he may experience will require him to use a safety belt and shoulder harness and these will also restrict his freedom of movement.

In this clothed condition the area in which the man can reach with his arms is considerably more limited than for the nude man or the man in shirt sleeves. Let us take a look at the useable control location area for a man restricted in this fashion. Figure 5 illustrates the work area of a seated pilot wearing a partial pressure suit.

Figure 5



Work Area of a Seated Pilot Wearing A Partial-Pressure Suit

The limit of his functional arm reach, i.e., the area where he can grasp controls, is 26". We must provide at least 12" of space on each side of the man for the man and his clothing and gear. With these restrictions the pilot has an actual work area with a maximum horizontal depth of 14". You can see how misleading the nude data of the anthropometrist can be. An example of the alterations the human engineer must make in this data is indicated in the next table. (Table 3)

Table 3

Arm Reach under Various Posture and Clothing Conditions

Condition	Size of Man	Arm Reach
Shirtsleeve, Standing	Large	37"
Shirtsleeve, Seated	Small	30"
Pressurized clothing, Seated	Small	26"

Referring to this table you will note that the large man (95th percentile) has an arm reach of about 37 inches as measured by the anthropometrist. The small man (5th percentile) must also be able to work efficiently and, when seated, his arm reach is only 30 inches. However, in our cockpit situation, wearing a pressure suit, his maximum functional arm reach will only be about 26 inches. This difference of 11 inches is a major discrepancy. It shows that failure to take into account the total equipment of the operator will result in grossly inefficient designs.

Human engineers in their attempt to design working environments to fit all, or nearly all operators, have found that designs can be arrived at which accomodate the middle 90% of operators without serious sacrifice of their efficiency. Those few men at the extremes can usually function with fair success under these conditions, and by ignoring, so to speak, the extremes in height, weight, and girth, the design of adjustable equipment such as seats, foot-rests, etc., is feasible.

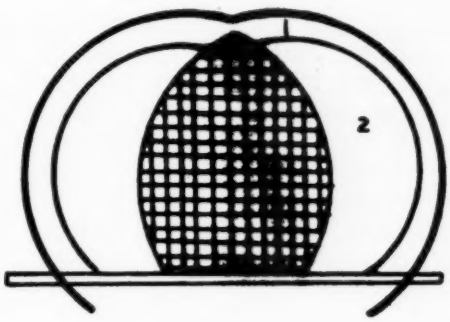
For this reason, the outer limit of the work area is determined by the arm reach of a man whose arm is shorter than 95% of men. (We say his arm reach falls in the 5th percentile.) The inner boundary is defined by the elbow room needs of the largest man we wish to accomodate -- the one who falls at the 95th percentile. By using these values we have defined the boundaries of a workplace in which the middle 90% of men can operate efficiently.

Further Area Delineation .

Three areas can be described within this total work area. This is shown in Fig. 6. This figure illustrates the working area on a vertical panel. Numeral 1 refers to an area for infrequent use

which can be reached only when the elbow joint is locked. Number 2 designates an area for frequent use, this area is easily reached by one hand. The cross hatched area is for controls to be used by both hands. These areas are smaller if the operator is seated because some mobility is lost and the size of the usable area also depends on the distance of the operator from the vertical work surface.

Figure 6



Work Area on a Vertical Surface Above a Bench

Anthropometrics and Workplace Adjustability.

Again, anthropometric data is used to define the optimum height of a work surface in front of an operator -- 12" above the seat level. In this case, average body measurement values have been used, but adjustability should be provided.

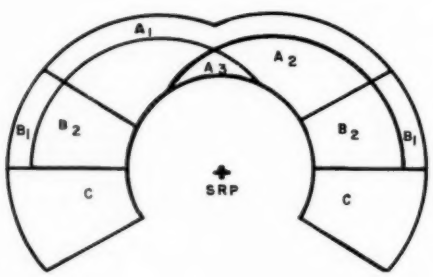
For instance, if we want to insure that most operators in a particular work situation have their elbows at the same level with respect to a flat work surface in front of them, making it equally easy for them to work there, we must make the seat in this work space adjustable. The short man's elbow level must be raised to this work surface, and the tall man's elbow level lowered. In order to do this the range of seat-to-eye heights (from 5th to 95th percentile) must be determined. This range turns out to be about 5 inches. In designing this seat, five inches of vertical adjustability should be incorporated, 2 $\frac{1}{2}$" up and 2 $\frac{1}{2}$ " down from the

normal position. You remember that an optimum average work surface height is 12" above the seat level, so the normal seat position should be 12" below the work surface. With five inches of adjustability, 90% of the population can place themselves in an efficient position in relation to the work surface. Of course, the seat could remain stationary and the adjustability be in the work surface itself. No matter which solution is used, the anthropometric data on which the degree of adjustability is based would be applied in the same manner. Here, then, is an example where both the average, and the maximum and minimum anthropometric values are used.

Combination of Perception and Anthropometrics.

Before closing, I would like to show you how data on perception and anthropometrics can be combined in order to provide more specific information about the design of work areas. We have already indicated in the cockpit slide that an area directly in front of the man can be delineated which will be seen with both eyes without the operator moving his head. Other visual conditions will further delineate this work area. Figure 7 presents work areas which satisfy both arm reach and visual data.

Figure 7



Anthropometrics and Visual Delineation
of Total Work Area

In this figure, the letters A through C designate visual areas within the work space. More head and eye movements are required to see objects in area C than in areas A and B. Thus area C can be considered less desirable from the standpoint of vision.

The subscript numerals, 1 through 3, identify breakdowns of the work space on the basis of arm reach data. To reach areas with the subscript 1, the elbow joint must be locked -- the arm is perfectly straight -- and the hand therefore has little flexibility, precise adjustments are difficult, and any control which requires much force will be difficult or impossible to operate. Areas with the subscript 2 are nearer the operator, more strength can be exerted there, fine adjustments are possible, and since little strain is involved in reaching these areas, controls operated frequently may be placed there. The area with the subscript 3 is appropriate for two-handed operations. As you can see, combining anthropometric and visual data has enabled us to define 6 areas on each side of the operator. The result is a more refined matching of control location and operator function.

In summary, perhaps we can best understand the contributions of perception and anthropometry to work efficiency by looking at man as one perceiving and responding link in a complex situation. The operator must be able to see clearly and understand the signals which are given him, either by other personnel or by the machine -- the input must be readable and unambiguous. In brief, we must see to it that the signals (auditory, visual, etc.) that an operator receives are optimum in all aspects that we can measure (size, distance, time, loudness, etc.). Once the signals are received, we must place the operator and the controls he operates in an optimum relationship to each other in order to make the response as fast and accurate as possible.

UTILIZING THE INDUSTRIAL ENGINEERING POTENTIAL IN MEDIUM-SIZED MANUFACTURING PLANTS

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The emergence of industrial engineering as a dominant and positive force in our industrial society can now be taken for granted. Certainly the current emphasis on automation and the many advanced industrial engineering techniques involved therein have strengthened the position of industrial engineering and have increased its opportunity to serve. The vigorous growth that the American Institute of Industrial Engineers has experienced for the past several years on a national level, the successful trend toward increasing the professional status of the industrial engineer, and the substantial and continuing demand for college graduates from the industrial engineering curriculum are indications that industrial engineering is gaining recognition in important places and that such recognition is deserved. To those who have pioneered in this, it is a heartening and rewarding development.

Yet, in spite of all this there is some concern that industrial engineering has taken on a sort of hybrid character. There are so many diverse techniques in the industrial engineering field -- process charts; flow diagrams; linear programmings; cost, motion, and organization analyses; operations research, and the like -- which lead to activity in such apparently different areas as wage and salary administration, production control, and work simplification (to name just a few) appear to some persons to reflect a "jack of all trades, master of none" trend which conceivably could dilute the effect of industrial engineering by causing it to become preoccupied with taking in more territory rather than in penetrating deeply into a less-encompassing domain.

Let me state at the outset that I do not share this concern. Rather, a purpose of this paper is to advance a somewhat opposite view which is that the industrial engineering function is not being fully exploited in many medium-sized businesses and, to the extent that less than optimum use of it is occurring, a case can be made that this is unnecessary, costly, and should be subject to considerably more attention by prudent management.

First, let us define the industrial engineering function. If we can accept the definition of industrial engineering as submitted by the A. I. I. E. Long Range Planning Committee at the Industrial Engineering Seminar at Cornell University last Fall and adapt it to this discussion, it would be as follows:

> The Industrial Engineering Function is that which "is concerned with the design, improvement, and installation of integrated systems of

men, materials and equipment; drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict and evaluate the results to be obtained from such systems."

Using this definition as a basis for this presentation, the main point of it can now be made which is that some of the major problems currently occurring in medium-sized business require re-examination within the framework of the industrial engineering function and that such re-examination will not only vindicate the apparent diversity of industrial engineering activity, but will substantiate the fact that certain management problems would be rendered easier for solution if it were recognized that they had a common industrial engineering base and if they were analyzed accordingly.

While it is readily conceded that such problems are not necessarily limited to those which will be listed below, this discussion shall be restricted to the following five problem areas:

1. The need for Planning as a routine operational technique.

   There can be, fundamentally, a significant difference between a company that has a planning department as an adjunct to some line department (such as production or engineering) and lets it go at that, and a company that really plans. Of course, it is possible to have both, and perhaps this is as it should be. But some medium-sized businesses do not have a concept of basic planning that can permeate the organization and so problems arise that take too much management time. What is distressing is that some of these problems could be conveniently placed within the area of the industrial engineering function to obtain both analysis and recommendations for action. This would have the advantage of not only relieving an already over-burdened management, but also of delegating the problem to experts where a solution should be forthcoming.

   As an example, a certain plant found itself with increasing orders of not inconsiderable size. These increased orders were taken with a delivery date in mind that seemed perfectly possible at the time the orders were received. However, it soon became apparent that the elapsed time from receipt of order to final shipment was getting longer and longer and promised dates were being missed. The question was, what to do? The Production Department claimed that the Engineering Department took too long to get the necessary drawings and specifications to it and consequently the production side was in no position to meet "impossible" delivery dates. The Engineering Department claimed that the Sales Department frequently did not provide information soon enough to allow completion of the technical requirements in time to meet the delivery date set up by the Sales Department itself. Both departments, Engineering and Production, felt they were

being pushed beyond what could be expected of them and perhaps the logical approach from their point-of-view might have been to extend the delivery dates. But that was not possible because the Sales Department, while admitting its fair share of responsibility, was sensitive to the fact that competition, coming from bigger plants, required even faster deliveries than were currently occurring. Consequently, the realism of this situation forced a focusing of attention toward the basis of the difficulty. Figure 1 shows the result of considerable analysis employing established industrial engineering techniques. Note that the problem was not solvable by any department independently. It was (1) interdepartmental and (2) technical. Hence, the solution required both a knowledge of organization as well as a technical background with which to evaluate the various factors involved.

Upon receipt of the customer order, the Sales Department fills out the section bracketed by A, and forwards the Production Schedule sheet on to the Production Scheduler who assigns practical deadline dates for the receipt of the necessary field information (of line B) and posts these dates on line C. The Production Schedule sheet then goes to the Production Engineering Scheduler ,who has the responsibility of scheduling (in cooperation with the departments involved) all items shown under "Schedule Dates (Through Engineering)" D. He signs the Schedule at E and returns it to the Production Scheduler who proceeds to make an analysis of the manufacturing problems to the extent of establishing a tentative scheduled shipment at F. This study includes a Production Analysis G which seeks to establish those critical items that will influence the delivery date. The Production Scheduler then signs the sheet at H and sends it to the Manufacturing Department for acceptance or rejection. Should the Manufacturing Department refuse to accept these dates it can"carry its case" to the General Manager (as any other department that finds a schedule unacceptable). No date later than that given in the "Customer Want Date" box J is permissable without its acceptance by the customer.

FIGURE 1 SCHEDULING JOB FROM RECEIPT OF SALES ORDER TO SHIPPING DATE

The importance here is not the specific solution but rather the technique employed. Here was the case of a smaller plant that had a serious problem and that had approached the problem on a sound, fact-finding basis that led to the application of sound systems and procedures. A larger plant probably would have long since solved this complex interdepartmental problem, not because the large plant was inherently smarter, but because the resulting confusion due to bigness would have placed it in the position where it would have had no alternative. In a smaller plant, however, such confusion might well have been regarded as "something a small plant has to live with". As in this case, such a decision would not have been justified. As can be seen, all of the pertinent information was available, but it had not been correlated and focused to be of help to this smaller plant until some procedure-minded technician did the job. It was not a question of plant size, it was just a question of facing a problem -- in this case, a rather involved problem -- with the type of competent personnel who could do something about it.

2. The need for Control as a dynamic philosophy within the organization.

Here again it is possible to have departments that specialize in the accumulation of information for control purposes but, unless there is an undergirding philosophy of control, a vital something is missing. Essentially, this is an indictment of management that has not grasped the full implication of the concept of Control and the need to organize for it effectively. Medium-sized plants are vulnerable in this regard, particularly where an owner-manager is very strong in one or two of the six major business segments -- which, for the purposes of this discussion are considered to be (1) merchandising (including market research), (2) engineering (including research and development), (3) general business (including finance, accounting, auditing, credit, and the like), (4) manufacturing (including procurement, etc.), and (5) human relations plus (6) organization -- but is relatively weak in the others. Since the company may not be large enough to require that each departmental function "stand on its own" and, therefore, may not include personnel who can give such a top executive strong support in all of these other functions, and because he may not necessarily be a student of Organization per se, then attempts to compensate for the ramifications of top-level unbalance may prove most difficult. It actually can and often does result in further loading the top executive rather than in causing a re-examination of the company structure to see if something new could be added to take care of this problem. The purpose of this paper is to point out that the exploitation of the industrial engineering function to an optimum degree would possibly provide a satisfactory basis for analysis and solution of these types of problems.

As a symptomatic example in this regard, it is possible to have rather elaborate cost systems yet not have the right information in the right place at the right time. Saying it another way, cost data can be historical

rather than dynamic; they can be excellent for reference purposes but have no inherent ability to assist in the quick solution of firing-line production problems. Another example of the use of Control can be illustrated by going a bit farther in the development of the technique that can be applied to achieve the delivery dates required in Figure 1. Obviously such delivery dates cannot be obtained simply by a piece of paper. Instead a point must be stressed here that careful analysis of all phases of manufacturing operations must be made and control must be established each step of the way to insure that a manufacturing schedule, once created, will be maintained. Again, this is done in most large plants as a routine necessity, yet many smaller plants have not recognized that the control of production on a rather "tight" basis is not a luxury. Figure 2 shows the basic control mechanism of a smaller plant which can maintain very close schedule control.

ROUTING (OPERATIONS) SHEET

JOB No 1032-2
PART No. 3 REVISION C DATE 3/12/53
MATERIAL 2½ RD C R S BY A.L.K.

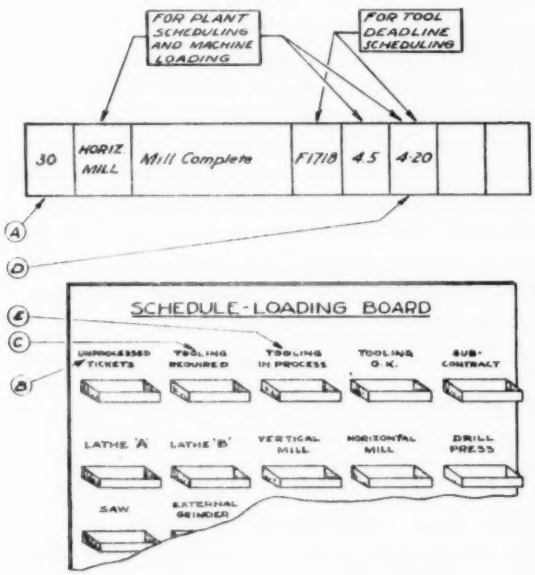
OPER No	OPER. NAME	DESCRIPTION	TOOL REQ	EST HRS	DATE DUE	INSPECT OK	
10	SAW	Cut to $12\frac{3}{8}$ $^{+\frac{1}{8}}_{-0}$		1.0	4-9		
20	LATHE A	Finish all over except bearing diameters Make them 1.810 1.800 Note class 3 threads	G 162 G 163	1.40	4-13		
30	HORIZ MILL	Mill Complete	F 1718	4.5	4-20		
40	INSPECT	Check Milling Contours	G 1719	-	4-21		
50	DRILL PRESS	Drill all holes	J 1720	3.5	4-27		
60	EXTERNAL GRINDER	Finish Bearing Diams to size		2.0	4-29		
70	STORES	To Subassembly Stores for Assy 2678		-	4-30		

FIGURE 2 ROUTING (OPERATIONS) SHEET

As stated previously, this is not shown to illustrate the exact arrangement that should be used in a plant, but rather it highlights the simple type of operation sheet that can be employed to serve as a basis for

coordination, planning and control. Operation sheets, of course, are not new. But many plants do not use them and many others are content to use just a part of a procedure that, if they went "all out" for Control, would practically guarantee to keep them out of these major types of trouble. Routing sheets are no panacea in themselves but they point the way to the kind of planning and control that prevents schedule difficulties before they start.

The question might be asked, how could this routing sheet be expedited to be sure that things were going as planned? One answer might be the arrangement as shown in Figure 2B.



Assuming the Operations Sheet (Figure 2) is made in duplicate, the second copy can be separated by operations as indicated above at A. These "unprocessed tickets" are then dropped in box B from which they are distributed to their appropriate other boxes. If they require no additional tooling, they are placed in the box corresponding to their operation name (in this illustration it is "Horizontal Mill") and can be scheduled based on completion date D.

If tooling is required, then the card will be placed in the "Tooling Required" box C. The person responsible for tooling scheduling will process these cards in order of priority established by completion date D. When the tooling is being worked on, the card will be in the "Tooling in Process" box E, and when it is completed it will be placed in the "Tooling O.K." box and subsequently, in the correct "operation name" box. (In actual practice, a colored duplicate is immediately placed in the appropriate "operation name" box for scheduling purposes while the regular card proceeds through the tooling program as described above. This allows scheduling to be done while at the same time the colored ticket indicates that tooling completion is required before the specific operation can get under way. This tends to expedite the tooling. The same procedure is used if subcontracting is employed.)

FIGURE 2b SCHEDULE-LOADING BOARD

What is being stressed here is that the management of the operations side of smaller plants -- or larger ones, for that matter -- is substantially a matter of good systems and procedures, and that the creation of such systems and procedures lies within the scope of the industrial engineering function.

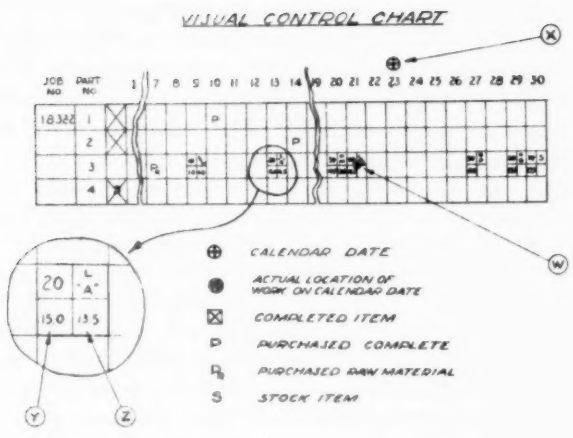
An important point should be made here which is this: Every single item shown on the Routing Sheet of Figure 2 or 2B is nothing more than the simple recording of a decision. The total sheet is the result of a whole series of decisions: How the operations are to be performed, in what sequence, what kind of tooling is to be employed, what date each step of the operation is to be performed, etc. Now, whether the plant is run at the very maximum of efficiency -- using the very best techniques of Systems, Procedures, and Control -- or whether it is the sloppies plant in the area using no operation sheets or other controls at all, every single one of these items has to be decided upon. It is not a question of short-cutting the decisions, for they have to be made in either case. Obviously, the use of the Routing Sheet requires that some one competent to make it will accomplish this task in advance of production. The nature of the form requires that consideration be given to those essentials that establish the minimum requirements for planning, and that this must be done in ample time ahead of actual operations to reduce the time pressure which, if the time element is ignored, usually leads to hasty decisions based on expedience rather than to decisions based on considered judgment. For in the poorly planned small plant, the best management talents are directed at getting out of trouble rather than staying out of it. A Routing Sheet is a technique for reversing this.

Another answer might be in having a visual control such as is shown in Figure 3. This is a control both for delivery date and direct labor cost.

It is difficult to make a major point of the importance of this without being sure that bench marks have been established. Viewing the manufacturing aspect of the plant solely, it performs its functions if it meets these two requirements: (1) it does work of acceptable quality on time, and (2) it does this work within the cost allowed. This goes for any plant of any size. Large plants establish rather elaborate controls to insure that these conditions will be met. A fact to be underscored here is that it would cost no more to install an adequate system for a smaller plant than it would cost to have no system at all. For no system at all is costly, so basic Control is not a luxury.

3. The need for technical adequacy throughout the organization.

This is an area whose importance can scarcely be overestimated. Yet, it can be observed that in many medium-sized or smaller industrial plants the significance of this is overlooked. No doubt, this is one of the problems



The object of this Visual Control Chart is to present the current situation in each case both with regard to (1) actual status in relation to scheduled delivery and (2) actual status in relation to estimated direct labor cost. So far as scheduled delivery control is concerned, this chart is no different in essentials from many others. It simply records daily the location of the work W for comparison with the actual calendar date X. However, with regard to direct labor cost control, this chart has some unique features. The estimated time is posted in the lower left hand corner of the box for each operation cumulatively at Y. (The posting time for this example is taken from the data in Figure 2, with the material data taken from Figure 6. It also assumes adequate time card control, and hence good direct labor basic cost data, such as is suggested in Figure 5.) Then, as the Part progresses through its cycle, actual time is posted in the lower right hand corner of the block at Z, also cumulatively, after each operation is completed. Consequently, it is possible to see on the one chart how each item of each job is progressing both with respect to (1) delivery date and (2) cost. Since this visual control can be prepared on duplicated sheets, it is not costly to set up yet it yields the basic information that is essential for good control of small operation-type manufacturing plants.

FIGURE 3 VISUAL CHART FOR CONTROL OF DELIVERY DATE AND DIRECT LABOR COST

that confront any business; but in at least some of the larger plants there is an awareness that something must be done about it.

It is no easy thing, this matter of a plant being technically adequate. To compound the problem, yesterday's adequacy is not sufficient for today's requirements; and we can anticipate that tomorrow's will be much more rigorous.

As an example, some years ago a manufacturer created a product that was very saleable. In the inevitable course of things he saw where improvements could be made here and there and, because he was technically minded (the inventor type) and was close to the manufacturing situation, he personally added these improvements from time to time. He said he did not need a complete Engineering Department, feeling that all he wanted was "someone to make the drawings". In those earlier days this arrangement worked out pretty well. Whatever changes came along were sketched out in the shop and were tested by placing them in production units. Now this was a good product, the improvements were good improvements and, in the space of a very few years, the product had achieved an international reputation and the plant facilities had greatly expanded. So far so good. But the attrition that comes with time was taking its toll and soon the original customers began to order replacements for the product. Parts

that were supposed to be correct were sent out by the company but the customers wrote back to complain that they did not fit. That stumped the Order Department and in subsequent correspondence with the customers it appeared that there was little correlation with the old records (such as they were) of the parts when compared with what the customer claimed he had. So this owner had to round up those persons who were still present from the "old days" in order to get suggestions as to what might be in the field units. In the resulting discussions it developed that any one of several possibilities existed. So the company was finally forced to write to the customers to explain that a drawing of the parts would be required if it was not convenient to send the original pieces themselves. Since some customers refused to shut down the equipment to provide either of these alternatives, it often became necessary for the company to send a man into the field to get the necessary information. As time went on the company was deluged by this sort of thing. This situation cost this company a lot of money and seriously affected dealer and customer relations.

The lesson to be learned here is that at the inception of the manufacturer's entry into this business the Industrial Engineering total function was ignored while emphasis was placed essentially on sales and manufacturing. This is not an unusual occurrence. Many smaller plants are operating in a manner equally dangerous by ignoring the requirements of technical accuracy in pre-production as well as in production stages. Actually, some of these plants are in such bad shape in this regard that any large success might almost be their undoing. For they are selling to their customers the types of products that will require the replacement of parts, yet practically no provision is being made to correlate the design with identification media to record historically the transition of changes of design, or any number of other things that will have to be faced in the natural order of things. For example, they may be changing tools which make the parts and they may be making no provision to record the tool changes. Or they may be changing inspection equipment and are not providing the historical correlation needed always to control the quality of parts to rerun from old designs. They may be failing to record technical processes whereby components of the product are created, they may be neglecting the need for specifications to control either their own or subcontractors' products, they may be overlooking the need for such simple but vital things as blueprints controls. Likewise there may be no recognition of the necessity to provide adequate part numbers or to maintain adequate parts lists. The long look toward the ultimate requirement of Standards may not even be considered.

Some of these problems have their amusing aspects. One medium-size manufacturing plant's Engineering Department had designed units that were right-hand and left-hand. For some reason it seemed important at the time to employ a part numbering system such that right-hand were even-numbered and left-hand were odd-numbered. Presumably, this semi-mneumonic system would be helpful. But as the product evolved, someone found a

way to reduce costs appreciably by a redesign that used right-hand parts, some left-hand parts, and converted both into a new design that was interchangeable, so far as right-hand and left-hand were concerned. Everyone was delighted until the attempt was made to reconcile the new situation with the old odd-even numbering system and all of the paper work that had been tailored to fit it. The result was a real headache for all concerned.

Another firm started out a new line of products employing a part numbering system with four digits. For assemblies a suffix (-1) was used; if there were a revision to the assembly it became (-2), etc. However, as time went on this company added part numbers until there were five digits. So it was then possible to have both a 1234-5 and a 12345. Internally, this posed no difficulty but in the field customers frequently ordered replacements without regard to the suffix. This, therefore, became a serious and continuing problem to the Order Department. Note the decision to use that specific numbering system apparently did not take account of the Order Department-customer relationship. Here again is an illustration of the need for the employment of the industrial engineering function at the inception of such a technical program to be sure that all of the problems within the departments involved can be anticipated and evaluated.

Technical adequacy is not just a matter of part numbers and bills of material. Like other major problem areas previously referred to, it is essentially a state of mind. And lack of it can drag down the overall organizational effectiveness. Broadly speaking, the important position the industrial engineering function can assume here is to assist management to achieve a realistic appraisal of the basic considerations involved so that appreciably better decisions can be made to the end that better inter-departmental relationships can result.

No function within an organization is potentially better equipped than industrial engineering to analyze such important cost items, for example, as the quality of the engineering drawings in relation to shop performance; or the adequacy of parts lists or bills of material in relation to material procurement, stores, and receiving inspection; or the adequacy of specifications and test data in relation to line inspection and quality control. In many medium size and smaller plants there is a very real need to close ranks on some of these knotty inter-departmental problems that frustrate management. The enlargement of the industrial engineering function can provide the positive steps toward the resolution of these difficulties.

4. <u>The need for continuing organizational planning, analysis and review.</u>

Lest this be considered far afield from the Industrial Engineering function I should like to refer to Peter F. Drucker in whose recent splendid book "The Practice of Management" we find this:

that were supposed to be correct were sent out by the company but the customers wrote back to complain that they did not fit. That stumped the Order Department and in subsequent correspondence with the customers it appeared that there was little correlation with the old records (such as they were) of the parts when compared with what the customer claimed he had. So this owner had to round up those persons who were still present from the "old days" in order to get suggestions as to what might be in the field units. In the resulting discussions it developed that any one of several possibilities existed. So the company was finally forced to write to the customers to explain that a drawing of the parts would be required if it was not convenient to send the original pieces themselves. Since some customers refused to shut down the equipment to provide either of these alternatives, it often became necessary for the company to send a man into the field to get the necessary information. As time went on the company was deluged by this sort of thing. This situation cost this company a lot of money and seriously affected dealer and customer relations.

The lesson to be learned here is that at the inception of the manufacturer's entry into this business the Industrial Engineering total function was ignored while emphasis was placed essentially on sales and manufacturing. This is not an unusual occurrence. Many smaller plants are operating in a manner equally dangerous by ignoring the requirements of technical accuracy in pre-production as well as in production stages. Actually, some of these plants are in such bad shape in this regard that any large success might almost be their undoing. For they are selling to their customers the types of products that will require the replacement of parts, yet practically no provision is being made to correlate the design with identification media to record historically the transition of changes of design, or any number of other things that will have to be faced in the natural order of things. For example, they may be changing tools which make the parts and they may be making no provision to record the tool changes. Or they may be changing inspection equipment and are not providing the historical correlation needed always to control the quality of parts to rerun from old designs. They may be failing to record technical processes whereby components of the product are created, they may be neglecting the need for specifications to control either their own or subcontractors' products, they may be overlooking the need for such simple but vital things as blueprints controls. Likewise there may be no recognition of the necessity to provide adequate part numbers or to maintain adequate parts lists. The long look toward the ultimate requirement of Standards may not even be considered.

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> There is no substitute for leadership but management cannot create leaders. It can only create the conditions under which potential leadership qualities become effective. . . The supply of leadership is much too limited and unpredictable to be depended upon for the creation of the spirit the business enterprise needs to be productive and to hold together. . . .
>
> . . . To talk of leadership as the unique key to spirit therefore only too often means neither action nor results.
>
> But practices, though humdrum, can always be practiced whatever a man's aptitudes, personality or attitudes. They require no genius -- only application. They are things to do rather than to talk about.
>
> And the right practices should go a long way toward bringing out, recognizing and using whatever potential for leadership there is in the management group. . . .[1]

This is penetrating thinking of a high degree and is very pertinent to this discussion. If Drucker is to be taken at face value, he is saying that a company would be wiser to put its dependence on organizational strength through good practices rather than to seek such strength through good leadership. Note, too, that a supplemental dividend is implied here, one that is most important in these critical days of short supply in management: good practices not only strengthen organization but establish a strong positive organizational environment that will greatly effect the development of management leadership potential. The importance in these circumstances is that good practices are what accomplish the task and good practices are, in a very real sense, synonymous with an important section of the definition of the industrial engineering function given earlier in this presentation. This validates the importance of strong organization through good practices and substantiates the strong position that the Industrial Engineering function should take in organizational planning, analysis and review.

5. The need for integration of human relations policies and operational practice.

Going back to the definition of the industrial engineering function, it was stated to be "concerned with. . . integrated systems of men, materials and equipment." Clearly this places an emphasis on the relationship of systems and people. The obligation of the industrial engineer in this

1. Peter F. Drucker, The Practice of Management, pp. 158-159. New York: Harper & Brothers Publishers, 1954.

situation is to "integrate" these, and integration by definition means to form a complete whole. So, in the final analysis, the industrial engineer has fulfilled less than his total function if he is content to consider his work complete when he has created the smooth procedure or even the right practice. His obligation goes beyond all this to the pivotal fact that human beings are involved and so he has to measure the success of his efforts not only in terms of technical effectiveness, but also in terms of another gauge whose calibrations are scribed by such terms as morale, motivations, empathy and the like. This is no mean task. Probably no other technician's professional function is as intimately tied to the individual and his relation to the work situation as is the industrial engineer's.

This is no new problem. Frederick W. Taylor was aware of the need of integrating persons and systems when, in recounting his classic Pig-Iron Experiment, he stated:

> Once we were sure that forty-seven tons was the proper day's work for a first-class pig-iron handler the task which faced us as managers under the modern scientific plan was clearly before us. It was our duty to see that the 80,000 tons of pig-iron were loaded on the cars at a rate of forty-seven tons per man per day instead of the twelve and a half tons, at which rate the work was then being done. And it was our further duty to see that this work was done without bringing on a strike among the men, and to see that the men were happier and better contented when loading at the new rate of forty-seven tons than they were when loading at the old rate of twelve and a half tons.[2]

This integration remains a problem, not because it has been ignored, but because it is of such tremendous scope that we have just begun to appreciate its vastness as well as its complexity and because we are just beginning to create the tools with which to cope with it. The significance to this discussion of the so-called Hawthorne Experiments is that they began as essentially research in the field of industrial engineering as it was then established but developed, as the researchers themselves reported, "in an unexpected fashion". As one of them stated:

> This statement -- the worker is a social animal and should be treated as such -- is simple, but the systematic and consistent practice of this point of view is not. If it were systematically practiced, it would revolutionize present-day

2. Frederick W. Taylor, The Principles of Scientific Management, pp. 42-43. New York-London: Harper & Brothers Publishers, 1911.

> personnel work. Our technological developments in the past hundred years have been tremendous. Our methods of handling people are still archaic. If this civilization is to survive, we must obtain a new understanding of human motivation and behavior in business organizations -- an understanding which can be simply but effectively practiced.[3]

There is this business of good practice again! Is not the industrial engineer in the best position to accept this challenge and to assist management to organize for effective action along the lines spelled out by the same reporter as follows:

> To preserve the social values existing in the cooperative system, the administrator needs skills of diagnosing human situations. To expect him to exercise effective control, to maintain authority, to obtain loyalty and confidence without such skills is to ask him to stay in a horse-and-buggy stage with regard to this aspect of his job when the remainder of it has long since become streamlined. It is our contention that these skills no longer need to remain intuitive and personal. They can be clearly formulated and applied. The introduction of these skills in our modern business organizations is the challenge of our times.[4]

Indeed, the integration of human relations policies and industrial operational practices is a fundamental problem of our times and the industrial engineering function is potentially in a better position to apply the skills that can solve this than any others. However, potential ability and preferred position are not enough. To do the job that has to be done the industrial engineer must have these skills personally. They must be not a part of his kit of tools, but rather must be a part of him. Nothing less will do the job.

My personal opinion is that the medium-sized and small plants have basic advantages over large plants in the field of human relations but this is just a theoretical advantage if positive action is not taken to assure that they are realized. The full utilization of the industrial engineering function along the lines suggested above should go a long way toward effecting this realization.

3. F. J. Roethlisberger, Management and Morale, pp. 25-26. Cambridge, Mass.: Harvard University Press, 1946.

4. Ibid., pp. 192-193.

Summarizing, I believe the Management of medium-size business would be well advised to do these specific things:

1. Analyze, in the light of the definition of the industrial engineering function, the major problems being faced to determine those that are encompassed within the framework of this definition.

2. Segregate those that can be considered within this industrial engineering function and re-examine them with a view toward consolidation.

3. Re-evaluate the personnel situation within the enterprise to verify that adequately trained and personally motivated persons are available to successfully cope with these problems; and, of course, if such persons are not available, to establish a plan of action to obtain them.

4. Plan, on a long range basis, the complete integration of the industrial engineering function in a staff relation to management.

If the restrictions of tradition were not excessively binding, this new-look approach conceivably could result in such unorthodox procedures as having the cost-accumulation functions reporting through production control (which is to say that the entire cost system would be primarily tailored to fit the needs of production rather than the requirements of the monthly income statement); or the strengthening of the systems and procedures functions by their integration into the broader industrial engineering function so that even the activities with such technical departments as design or production engineering would be correlated into the total plan; or any number of other creative, imaginative, dynamic new approaches to old situations.

There is a lot being said these days regarding the problem of Coordination which is, by all odds, the supreme problem of Organization; and also the problem of Communication which is the means of accomplishing Coordination. At this critical time in the evolution of dynamic administration, it would be well for business generally to embrace the industrial engineering function which, probably more than any other, has the potential to directly come to grips successfully with many of the technical and quasi-technical procedural problems -- both on the plant firing line and in the office -- that are so intimately associated with Coordination and which so desperately require solution. May I respectfully suggest that Industrial Engineers would do well to reflect upon the implied challenge herein. It may indeed be the field of their greatest opportunity for greatest service.

VIBRATION, SHOCK AND NOISE CONTROL FOR PRODUCTION EQUIPMENT

by
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As machinery speeds are increased, as working tolerances become more rigid, and as the electronic controls for machinery become more and more sensitive, the need for effective vibration and shock control becomes greater and greater.

There was a time, however, when we thought only of vibration isolation. Today there are many other remifications of machinery mounting. The following are typical benefits which can be obtained with properly designed machinery mountings:

1. IMPROVED PLANT ARRANGEMENT: The use of proper machinery mountings facilitates better plant integration with the straight-line work flow method of materials handling. For example, instead of "hiding" impact machinery, such as forging hammers and punch presses in a separate part of a building, and then transporting the materials from them to the precision finishing machines such as grinders and boring machines, the impact and precision machines can now be located side-by side provided either or both of them are installed on properly designed machinery mountings. Such mountings often also permit installation of impact and precision machines on weak upper floors where their use would otherwise be impossible. A typical example of improved plant arrangement is illustrated in Figure #1.

2. MACHINERY MOBILITY: In these days of rapidly changing production lines, fast installation and rearrangement of machinery is of great importance to many manufacturers. Proper machinery mountings, in most cases, eliminate the need for bolting machines to the floor and often pay for themselves immediately by reducing initial installation costs. In many cases, they eliminate heavy concrete foundations which would otherwise be required under the machines. Consequently, most machines when properly mounted can be picked up and moved to a new location by means of a fork lift-truck and can be back in operation within a matter of minutes. See Figure #2. Another benefit provided by many machinery mountings is built-in leveling screws which eliminate the need for shims and provide a much faster method for leveling the equipment.

3. INCREASED SPEEDS AND PRODUCTION: Many machines, such as high-speed punch presses, cannot be operated at their maximum speeds and output because the shock transmission to the building and surrounding precision equipment becomes excessive. By absorbing this shock, machinery mountings often permit greatly increased speeds and production. See Figure #3.

4. REDUCED MACHINERY DOWN TIME: Vibration and shock from one machine may make it impossible to operate other nearby machines, or may so greatly increase the wear on precision machines that time lost for maintenance interfers with production. Proper machinery mountings in some cases have more than tripled the life of bearings on precision boring machines, increased bearing life on punch presses, and greatly increased rod life on steam drop hammers, as typical examples. One such installation is illustrated in Figure #4.

5. VIBRATION AND SHOCK CONTROL: Where the problem is solely that of preventing objectionable vibration or shock transmission from an offending machine, this can be accomplished with properly designed machinery mountings. For example, the shock absorption provided by the spring-isolated hammer foundations shown in Figure #1 is so effective that a dime will remain balanced on edge right beside the foundation as maximum die-to-die blows are struck! It is impossible to feel any shock transmission to the floor from punch presses mounted on spring Isolators such as those shown in Figure #3. If it is impractical to resiliently mount the disturbing equipment, as in the case of shock and vibration created by railroad trains and passing trucks, then resilient mountings for precision machines will protect them against these disturbances.

6. REDUCED REJECTS: A startling number of rejects are not the fault of the operator or the machine. Rather, it is vibration -- from other machinery, from passing fork trucks, and from many other outside sources -- which is the culprit. When precision machines are installed on weak upper floors which deflect as loaded trucks go by, the deflection leaves the machine unsupported, as illustrated in Figure #23. This results in distortions and inaccuracy in the work. Properly designed resilient machinery mountings can completely prevent these difficulties.

7. REDUCED NOISE, INCREASED EMPLOYEE EFFICIENCY: Excessive vibration and noise have a very decided influence on the nervous system and contribute materially to mental and physical fatigue, often resulting in loss of production because of accidents and employee absentism. The very serious problem of occupational hearing loss is emphasized by the fact that millions of dollars in claims are now pending against companies, and the awards already made to employees run into the hundreds of thousands of dollars. In some cases, vibration and shock control for machinery provides virtually a complete solution to the problem of transmitted noise. However, in most cases machinery mountings provide a very helpful part in the overall treatment required in a successful noise reduction program, as explained later in this paper.

All of the above benefits will be explained in greater detail and illustrated in the following pages. However, it is first desirable to consider the basic theory of vibration and shock control, and the different types of vibration and shock mountings.

THEORY OF VIBRATION CONTROL

A very simple equation applies to determining the transmission of steady-state vibration, the constantly repeating sinusoidal wave form of vibration generated by such equipment as compressors, engines, pumps) hammermills, centrifuges, and vibrating screens:

$$\text{Transmissibility, T, } = \frac{F_t}{F_d}$$

$$= \frac{1}{\left(\frac{f_d}{f_n}\right)^2 - 1} \quad (1)^{**}$$

where f_d = frequency of disturbing vibration, cycles per minute (cpm)

f_n = natural frequency of the resiliently mounted system, cpm

f_d = unbalances force acting on the resiliently supported system

f_t = force transmitted through the resilient mountings

$$f_n = 188\sqrt{\frac{1}{d}} \qquad (2)$$

where d = static deflection of the resilient mounting in inches

$$d \quad \frac{W}{k} \qquad (3)$$

where W weight on the mounting

k stiffness factor of the mounting in lbs/in. of deflection.

**This equation is exact for steel springs because they have straight-line load deflection characteristics and negligible damping. When the equation is used for organic materials, the following corrections will normally give conservative results: For rubber and neoprene, use 50 percent of the static deflection when calculating f_n. For cork, use f_n equal to one and one-half times the natural frequency determined by actual test.

The natural frequency, or f_n, of a resiliently mounted system is the frequency at which it will oscillate by itself if a force is exerted on the system and is then released. This can be illustrated by suspending a weight from a very long rubber band. The longer the rubber band the more deflection the weight produces in it. If the weight is then pulled down slightly by hand and released, it will oscillate up and down at the natural frequency of the system. The more deflection in the system, the lower is the natural frequency of the system. The importance of this can be seen by reexamining equation 2 rewritten in the following form:

$$F_t = F_d \left[\frac{1}{\left(\frac{f_d}{f_n}\right)^2} - 1 \right] \qquad (4)$$

Obviously, we want to minimize the transmitted force, F_t. Since the disturbing force, F_d, is a function of the machine characteristics and cannot be reduced except by dynamic balancing of the machine (or by reducing the operating speed, which is seldom practical) the transmitted force can be reduced only by maximizing the quantity

$$\frac{1}{\left(\frac{f_d}{f_n}\right)^2} - 1$$

This can be accomplished only by increasing the frequency ratio, f_d/f_n. However, since the disturbing frequency, f_d, is fixed for any given machine and is a function of the rpm, it can seldom be changed. The only remaining variable is the mounting natural frequency, f_n. Reducing f_n by increasing the static deflection of the resilient mountings reduces the vibration transmission. This explains why the efficiency of machinery mountings increases as their resiliency and deflection increases.

Figure 5 shows the effect of varying frequency ratios on the transmissibility. Note that for $f_d/f_n < \sqrt{2}$, the use of mountings actually increases the transmissibility above that which would result if no insulation were used and the machine were bolted down solidly. In fact,

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or A system may have up to six natural frequencies, but it will be found that in the practical selection of machine mountings, if the vertical natural frequency of the system is made low enough for a low transmissibility, the horizontal and rotational natural frequencies will generally be lower than the vertical and can be disregarded except on machines with very large horizontal unbalanced forces or with large unbalanced moments, e.g., horizontal opposed, large two-, three- and five-cylinder engines, etc.

if careless selection of the mount results in a mounting natural frequency equal, or nearly equal, to the disturbing frequency, a very serious condition called 'resonance' occurs; in equation 4 the denominator of the transmissibility function becomes zero and the transmitted force F_t, theoretically becomes infinite. As the ratio f_d/f_n decreases beyond $\sqrt{2}$, the resilient mountings reduce the transmitted force. Table I gives some suggested maximum design transmissibilities for different types of job conditions. Figure 6 shows a chart which can be used to select the proper resilient mountings when the following job characteristics are known: weight per mounting, disturbing frequency, and design transmissibility. The chart shows the limitations of the various types of isolation materials, particularly helpful data in selecting the proper media.

SHOCK ABSORPTION FOR IMPACT MACHINES

Shock absorbing mountings are not selected on the basis of the data and equations shown above. In shock absorption, the mountings change the sudden damaging impact to a smaller, gradually applied force. In shock mountings, the natural frequency of the mountings is actually greater than the disturbing frequency, or strokes per minute, of the impact machines. Maximum shock absorption is obtained by keeping the mounting as soft as possible (f_n as low as possible, but not less than 1.5 f_d because resonance must be avoided). Figure 7 illustrates that the more resilient mountings, providing more static deflection, result in smaller forces transmitted through the mountings. Since resonance must be avoided in shock absorption too, the calculator in Figure 6 contains a line marked "For Shock Absorption Stay Above This Line."

In addition to the loud noise produced when the dies strike the work, impact machines such as punch presses, drop hammers, forging hammers, and similar machines also create noise generated by the transient high-frequency vibration of the press parts induced by the initial shock. A secondary noise source results from floor and wall panels vibrating as diaphragms when set in motion by the initial shock. Structural transmission of the initial shock with accompanying noise, and generation of the secondary noise can be eliminated through the use of resilient mountings under these impact machines (see Figure 8).

TYPES OF VIBRATION AND SHOCK MOUNTINGS

Cork was the original vibration and noise isolation material and has been used for this purpose for at least a hundred years. The most widely used form of cork today is compressed cork made of pure granules of cork without any foreign binder, compressed and baked under pressure with accurately controlled density. Cork can be used directly under

machines, but its widest application is under concrete foundations (see Figure 9). It is not affected by oils, acids normally encountered, or temperatures between 0° F and 200° F, but it is attacked by strong alkaline solutions and will rot under continuous cycles of moistening and drying. Cork under concrete foundations still giving good service after twenty years indicates a long, useful life when properly applied. Cork is fairly good as a low-frequency shock absorber, but its use as a vibration isolator is limited to frequencies above 1800 cycles per minute. Cork has good sound-insulation characteristics. Because of the large amount of damping in cork, the natural frequency cannot be computed from the static deflection and must be determined in tests by vibrating the cork under different loads to find the resonance frequency, which establishes the natural frequency of the material. The limiting values for cork given in Figure 6 were determined in this manner.

Rubber has very good sound-insulation characteristics, is fairly good for low-frequency shock absorption, and is useful as a vibration isolator for frequencies above 1200 cpm. Typical rubber mountings and combination rubber and cork mountings are illustrated in Figure 10. Rubber is not affected by acids or alkalis, but is not recommended for use in the presence of sunlight. The temperature range of natural rubber is 50 to 150° F; that of neoprene, 0° to 200° F. Neoprene rubber is recommended for applications where there is continuous exposure to oil. Special rubber compounds are available to meet conditions beyond those cited. Rubber tends to lose its resiliency as it ages. The useful life of rubber mountings is about seven years under non-impact and about five years under impact applications, though it retains its sound insulation value for much longer. Individual molded-rubber mountings are generally economical only with the light and medium-weight machines, since the heavier-capacity mountings approach the cost of the more efficient steel spring isolators. Pad-type rubber isolation has no such limitations.

Steel spring isolators provide the most efficient method of isolating vibration and shock, approaching 100-percent effectiveness. The higher efficiency is due to the greater deflections which they provide: standard steel spring isolators such as those shown in Figure 11 provide deflections up to 1¼ in. compared to about ½ in. maximum for rubber and other materials, while special steel spring isolators can give deflection up to 10 in. Since the performance of steel springs follows very closely the equations of vibration control, their performance can be very accurately predetermined, eliminating costly trial and error which is sometimes necessary in other materials. Steel spring isolators are generally equipped with adjustable snubbers, since steel springs, themselves contain no damping. (Damping is sometimes useful in limiting the movement of resiliently mounted machines, but damping reduces the isolation efficiency of the mounting.) Most steel spring isolators are equipped with built-in leveling bolts, which eliminate the need for shim

when installing machinery. The more rugged construction possible in steel spring isolators provides for a long life usually equal to that of the machine itself. Since high-frequency noises sometimes tend to by-pass steel springs, rubber sound-isolation pads are usually used under spring isolators to stop such transmission into the floor on critical installations.

Table II tabulates the useful range of cork, rubber, and steel springs for different equipment speeds.

DIRECT MOUNTING VS. CONCRETE FOUNDATIONS: Most machines can be mounted directly on the vibration or shock mounts. In fact, their use frequently eliminates the need for heavy foundations under machinery. However, equipment should be mounted on a foundation supported in turn by the isolation rather than directly on the isolation, when the foundation is to serve one or more of the following purposes: (1) reduce movement of equipment subjected to impact energy, such as drop hammers, forging hammers, foundry jolters; (2) reduce oscillation of equipment subjected to periodic forces and moments, such as low-speed diesel engines, horizontal compressors, laundry extractors; (3) reduce tilting of equipment where heavy parts of the machine are moved, such as roll grinders and large surface grinders; (4) prevent distortion and misalignme of equipment made up of several parts, or with beds not rigid enough to b supported directly on mountings, such as large lathes, large shears, and some large engine generator sets (in some cases, a structural steel base can be used instead of concrete foundation for this purpose); (5) increase mass and stability for delicate equipment and instruments, such as optical comparators and micro-balances. The foundation in itself does not reduce the amount of vibration transmitted through the isolation. The increased mass simply limits the amount of movement, which might otherwise be objectionable to the machines operator or cause excessive vibration transmission through semi-resilient connections, such as piping, between the machine and building. The piping should be considered analagous to a cantilever beam where the force is proportional to the movement. By reducing the movement of the equipment and piping through the use of a concrete foundation, the force transmitted through the piping is also reduced.

PRACTICAL APPLICATIONS

Reciprocating Equipment: Most high-speed engines (over 900 rpm) of the 1, 2, 3, 4, 6 and 8 cylinder types, and most pumps and refrigerating and air compressors operating at speeds above 450 rpm can be supported directly on isolation mountings without a concrete foundation with an arrangement similar to that shown in Figure #12. However, the unbalance in high-speed 1, 2, 3 and 4 cylinder engines will result in considerable movement of the equipment, and all piping and wiring should be flexible.

Even reciprocating machines, such as vibrating screens, can be supported directly on the Isolators as shown in Figure #13, and the use of mountings generally permits installation of this equipment high in the building without foundations or structural reinforcement, resulting in substantial economies due to gravity flow of the materials down through these processing plants.

However, certain types of reciprocating machines do require concrete foundations. This particularly is true of large, slow-speed engine generators which require foundations both for rigidity and to reduce the amount of movement otherwise created by the large forces and couples. Knowing the magnitude of the unbalance in the equipment, it is possible to calculate the foundation mass required to limit the movement to any required amount. Large engine foundations often weigh three times as much as the equipment; in large horizontal compressors and vacuum pumps, such as shown in Figure #14, the unbalance is often so great that the foundations must weigh as much as six times the equipment weight. On multi-cylinder air and refrigerating compressors driven by motors of more than 75 hp, it is generally found that the unbalance in these machines is great enough to warrant the use of a foundation weight approximately equal to that of the equipment in order to limit the movement of the piping.

Since most machines of the reciprocating type operate at speeds below 1200 rpm, with a few running up to 1800 rpm, it can be seen from Table II that in most cases steel spring Isolators are required for the highest isolation efficiency. The larger deflections and lower natural frequencies obtainable with spring Isolators permit isolation of unbalance occurring at rpm of the equipment, as well as the higher harmonics. Rubber mountings have a limited application for non-critical installations under the above equipment when operating at speeds above 1200 rpm. Cork has such a high natural frequency that it will seldom isolate primary unbalance, and its use is limited under such equipment to massive machinery foundations in non-critical areas where the cork isolates only the higher harmonics and prevents noise transmission. In non-critical locations, cork is used as a shock-absorbing material on horizontal compressors and vacuum pumps as shown in Figure #15.

Rotating Equipment: Rotating machinery, such as centrifugal compressors, pumps, turbines, exhausters, blowers and electric motors, is generally better balanced statically and dynamically than reciprocating machines. Other rotating machines, such as mills, pulverizers, centrifuges, crushers and similar equipment are fairly well balanced when new, but rather quickly become unbalanced in the field due to the rugged service which causes wear, and due to accumulations of the processed material on the rotating parts. The first group of high-speed machines mentioned above can often be effectively isolated with rubber or cork, though in

critical installations the use of springs is still often justified since the high frequency vibration generated by these machines frequently is in resonance with portions of the building structure, requiring transmissibilities of less than 10% in critical locations to prevent trouble.

The second group of slower speed rotating machines generates far more vibration because of the materials they handle, and the much higher efficiency and longer life of spring Isolators generally is warranted on such installations, particularly when the machines are installed on upper floors.

Concrete foundations are seldom required under either type of these rotating machines to limit the movement, but they are sometimes used, as in the case of centrifugal refrigeration machines, to provide a rigid support for both the equipment and the driving motor. Typical installations of both types are shown in Figures #16 and #17.

Impact Machinery: Impact machinery generates shock which in itself is damaging but which also induces transient vibration of the impact machine, the building floor and other equipment, each at its own natural frequency which is usually very high and damaging. These transient vibrations are of particular interest in the shock mounting of sensitive equipment to protect it against shock from outside sources, as explained later. The initial shock produced by impact machines is also of great importance because of the actual physical damage which it causes to buildings and machinery. Shock absorption for impact machines is simply a matter of slowing down the rate of energy delivery to the structure from the impact machine. A shock mount changes an impulsive shock to a gradually applied force, and if the time of application is made long enough, the shock can neither be felt nor produce damaging accelerations in the structure and other machinery. This principle can be demonstrated by dropping a small cloth bag filled with buckshot down the inside of a guiding tube until it lands on a light bulb which will break because of the sudden delivery of energy. This energy is equal to the weight times the height from which it is dropped. If the cloth sack is opened and the buckshot are poured slowly from the same height and fall a few at a time on the light bulb, the amount of energy delivered is the same, but the light bulb will not break because the energy is delivered over a much greater period of time, which is the principle utilized in shock mountings.

Shock mountings for hammers, punch presses, drop test machines and similar equipment dissipate the residual impact energy (after the blow energy has been delivered to the work in a properly designed system) by the movement of the equipment on the shock mountings. The more resilient the shock mountings, the less force transmitted to the substructure as illustrated in Figure #7.

Most presses, including even the largest automotive body presses, can be mounted directly on isolation materials as shown in Figure #3. For the highest efficiency, steel springs are used, with rubber mountings and pads satisfactory for less critical installations, except that the shock generated by presses over about 60 ton capacity is generally sufficient to warrant the use of spring Isolators. On very high crank type presses with a narrow spacing between the front and back legs of the press, it is sometimes necessary to use a structural steel base to spread out the mountings in order to prevent rocking of the press.

Figure #1 illustrates the spring-isolated type of concrete foundation for hammers first introduced by the Korfund Company about 1937. This method of shock absorption has been extremely successful. Well over 500 hammers of all types ranging up to 25,000# capacity steam drop hammers are installed in this manner all over the world. Use of such foundations frequently makes it possible to install hammers on poor soil without the piling which would otherwise be required.

Our latest research in the field of shock absorption for hammers is along the lines of eliminating the concrete foundations entirely on at least the smaller gravity drop hammers. A typical installation of this type is shown in Figure #18.

Machine Tools: Machine tools fall into two categories -- those which create vibration and those which are adversely affected by vibration from outside sources. For example, a shaper or milling machine generates vibration due to the action of the cutters. Precision grinders and boring machines are examples of equipment adversely affected by external vibration. Some machine tools fall into both classifications: a lathe or grinder may generate serious vibration when taking rough cuts but will then be adversely affected by external vibration when taking fine finishing cuts. Fortunately, the same mountings which stop transmission of the objectionable vibration from the machine during rough cuts will prevent transmission of external vibration into the machine when it is taking finishing cuts.

Figure #19 illustrates typical treatment of a machine tool generating vibration. Unless the machine is on an upper floor in a very critical location, rubber mountings are generally adequate. Thousands of machine tools are being installed today on mountings such as those shown in Figure #10 (E) and (F) where there is little or no problem of vibration transmission into or from the machine. The materials are being used to simply eliminate the need for bolting the machines down or to provide for quick leveling. The result is greater flexibility of plant layout, equipment mobility and greatly reduced equipment installation time and cost.

On the other hand, with the constantly increasing emphasis on closer tolerances and better finishes, the need to protect precision machines against external vibration has greatly increased. We refer to this as "negative isolation." When sensitive equipment is being mounted to protect it against vibration by some definitely known piece or rotating or reciprocating machinery of the types cited previously, then the mounting for the precision machine is designed to isolate the lowest disturbing frequency generated by the disturbing machine.

In many cases, the problem is to protect precision machines against shock and the random type of vibration created by passing trucks and trains. In such cases, shock from the impact machine appears as a shock in the sensitive equipment, plus high frequency transient vibration of the floor and machine tool parts at their own natural frequencies. This is illustrated in Figure #20. Since the floor and machine parts vibrate at very high frequencies and since the magnitude of the acceleration resulting from this vibration is proportional to the square of the frequencies, the accelerations can be quite substantial and are responsible for skips, gouges and other inaccuracy in the work of precision machines which are not protected against external impact.

When the sensitive equipment is mounted on resilient mountings (preferably springs) the initial shock in the floor simply causes a gradual displacement of the equipment which then goes into transient vibration at the low natural frequency of the mountings. This frequency is so low that the accelerations produced are so small that the equipment is completely unaffected. At the same time, the mounting system is providing vibration isolation to protect the sensitive equipment against the high frequency transient vibration set up in the floor by the initial shock illustrated in the middle curve of Figure #20.

This effect can be demonstrated by fastening a light bulb socket to the end of a steel rod clamped at the other end in a vise to form a cantilever beam which will vibrate like a reed if displaced and then released. If the cantilevered rod is short, the natural frequency will be very high, simulating the vibration of component parts of the non-isolated machine tool subjected to transient vibration following an initial shock. The high frequency vibration produces large accelerations in the lamp filament which quickly burns out. However, if the cantilevered rod is made much longer, the natural frequency of oscillation is very low and the corresponding accelerations are reduced so greatly that the lamp bulb will oscillate back and forth indefinitely without breaking and burning out the filament. This latter condition is analagous to the resiliently mounted machine tool oscillating at a much lower natural frequency as shown in the lower graph of Figure #20. The fact that the same demonstration can be accomplished by mounting a microswitch at the end of the rod which will rapidly open and close the electrical circuit when subjected to high frequency vibrations indicates why many companies have difficulties with their electrical controls on machinery which is subjected to severe vibration and shock.

Figures #4, #21 and #22 illustrate how precision machines can be mounted directly on resilient supports to protect them against such vibration and shock.

Figure #23 shows why steel spring mountings under precision machines installed on weak upper floors often permit installations which would otherwise be impossible. When a machine tool is installed without resilient mountings on a weak upper floor which deflects as loads are placed nearby on the floor or as a loaded truck passes by, the floor deflects, leaving the machine tool bed completely unsupported as shown. This sets up strains and distortions of the bed which frequently result in rejects on precision work. On the other hand, when the machine tool is mounted on steel spring Isolators, as the floor deflects, the springs simply lengthen to compensate for the floor deflection and still provide substantially undiminished support for the machine at these points.

Laboratory and Other Delicate Equipment: Optical comparators, gear checkers, comparators, electronmicroscopes, electronic control panels and many other types of equipment can be protected against external vibration in the same manner outlined for machine tools. Steel spring Isolators would be used for the highest efficiency with rubber or cork mountings satisfactory for fairly non-critical installations.

Concrete Foundations in Negative Isolation: Most machine tools can be mounted directly on the isolation mountings without any concrete foundation. This is also true of many of the more sensitive types of equipment, such as electron microscopes, which have a great deal of mass due to their weight. However, some machines require concrete foundations for structural rigidity (such as roll grinders and long lathes). Resiliently mounted foundations are also recommended for lightweight, highly sensitive equipment (such as laboratory balances) for two purposes: (1) to provide stability to lightweight equipment, particularly where operators must exert forces on it while using the equipment, and (2) to damp out any small amount of residual vibration which may get through the Isolators. Typical installations of this type are illustrated in Figures #24 and #25.

NOISE REDUCTION: Machinery mountings in some cases provide virtually a complete solution to the problem of transmitted noise, particularly to the floor below the machinery, and, to a lesser degree, to the rooms adjoining the machinery room, or if the problem involves vibration and noise transmission from pipe lines. However, in most cases, vibration and shock control for the equipment is not a complete solution, but is only a part of the overall treatment required in a successful noise reduction program. For example, resilient machinery mountings are often used in conjunction with acoustical baffles, sound hoods, acoustical treatment of walls, etc. to produce the desired reduction in noise levels.

Figure #6 shows how resilient mountings prevent structural noise transmission and diaphragm-generated secondary noise sources. In one installation involving 20½ special punch press type machines located on an upper floor, installation of rubber pad type mountings reduced the noise level within the room itself by approximately 8 decibels.

Piping Vibration and Noise:

Vibration and noise transmission through piping, particularly on air-conditioning installations, is a serious problem. When refrigerating compressors are installed on resilient mountings, provision should be made for flexibility in the discharge and intake piping to reduce vibration transmission. This can be accomplished either through the use of flexible metallic hose (which must be of adequate length and very carefully installed in strict accordance with the manufacturer's specifications) or by providing for flexibility in the piping itself. This is often accomplished by running the piping for a distance equal to 15 pipe diameters both vertically and horizontally before attaching the piping to the structure.

Additional protection is provided by suspending the piping from the building on resilient hangers or by supporting it from below on resilient mountings. Flexible rubber hose approximately three diameters long should be used on the intake and discharge sides of water pumps. Flexible duct connections should always be used on the intake and discharge of fans, and such flexibility should not be nullified by subsequently covering the duct with rigid insulation on air-conditioning installations.

Effective vibration and shock control for machines is generally quite inexpensive, seldom exceeding 3% of the equipment cost. In many cases, resilient mountings pay for themselves immediately by eliminating special machinery foundations or the need to bolt equipment to the floor. It is much cheaper to prevent vibration, shock and noise transmission by installing mountings when the equipment is installed than it is to go back later and try to correct a faulty installation. For this reason, it is important to anticipate and prevent serious problems through the use of the proper types of machinery mountings.

Table I—Maximum Allowable Design Transmissibilities

In quiet surroundings, on upper floors, and in similar areas, more effective isolation is required. Installations near column footings or load-bearing walls may transmit vibrations up into floors above. Below are given the general ranges of allowable vibration transmissibilities for different job conditions.

(a) *Extremely Critical Conditions:* Large heavy machinery in penthouses, directly over offices, libraries, hospital rooms, on resilient mezzanines, etc.—maximum tolerable transmissibility, 10%.

(b) *Critical Conditions:* All upper floor installations, except the extremely critical ones above. Also some ground-floor installations near quiet areas in hospitals, broadcasting studios, libraries, etc. The bulk of installations requiring steel spring isolators fall into this category—maximum tolerable transmissibility, between 10% and 20%.

(c) *Non-Critical Conditions:* Installations in basements, on ground floors (except as above), in industrial areas where some vibration transmission can be tolerated because of greater building or ground mass to absorb it, greater ambient noise level, and distance from any critical areas. This is typical of the range generally covered by rubber and/or cork—maximum tolerable transmissibility, between 40% and 60%.

Table II—The Relative Effectiveness of Steel Springs, Rubber, and Cork in the Various Speed Ranges.

Range	rpm	Springs	Rubber	Cork
Low	Up to 1200	Required	Not recommended except for shock *	Unsuitable except for shock *
Medium	1200–1800	Excellent	Fair	Not recommended
High	Over 1800	Excellent for critical jobs	Good	Fair to good

* For non-critical installations only; otherwise, springs are recommended.

FIGURE #1. Cutaway view shows spring suspended foundation for steam drop hammer. Insulators Insolators prevent all shock transmission from the hammer and permit installation of precision finishing machines nearby for straight line work flow.

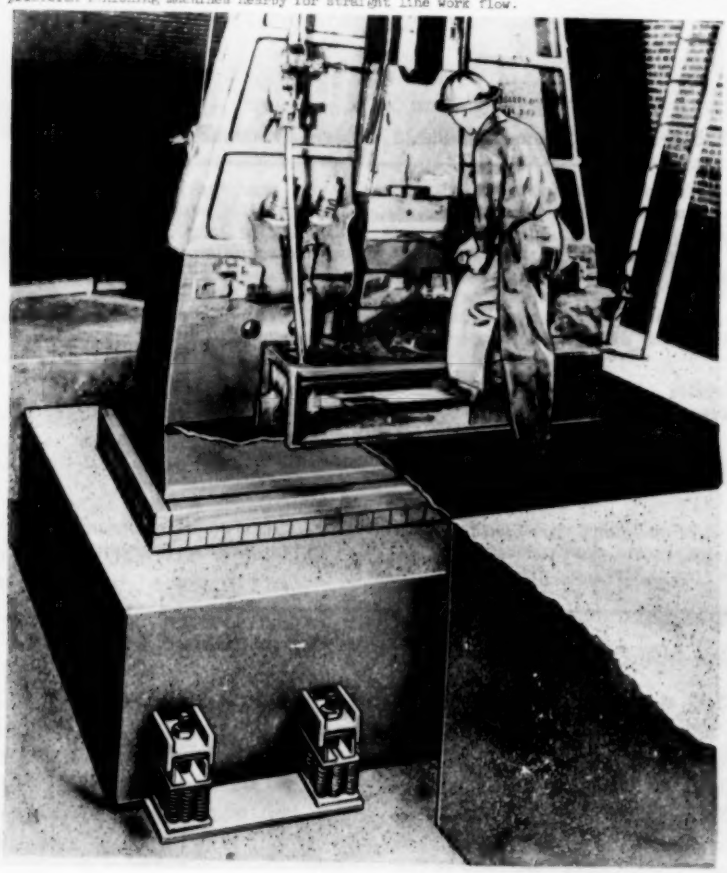


FIGURE #2. Machinery mountings eliminate lagging machines to floor, speed up installation, and permit quick re-arrangements of machinery.

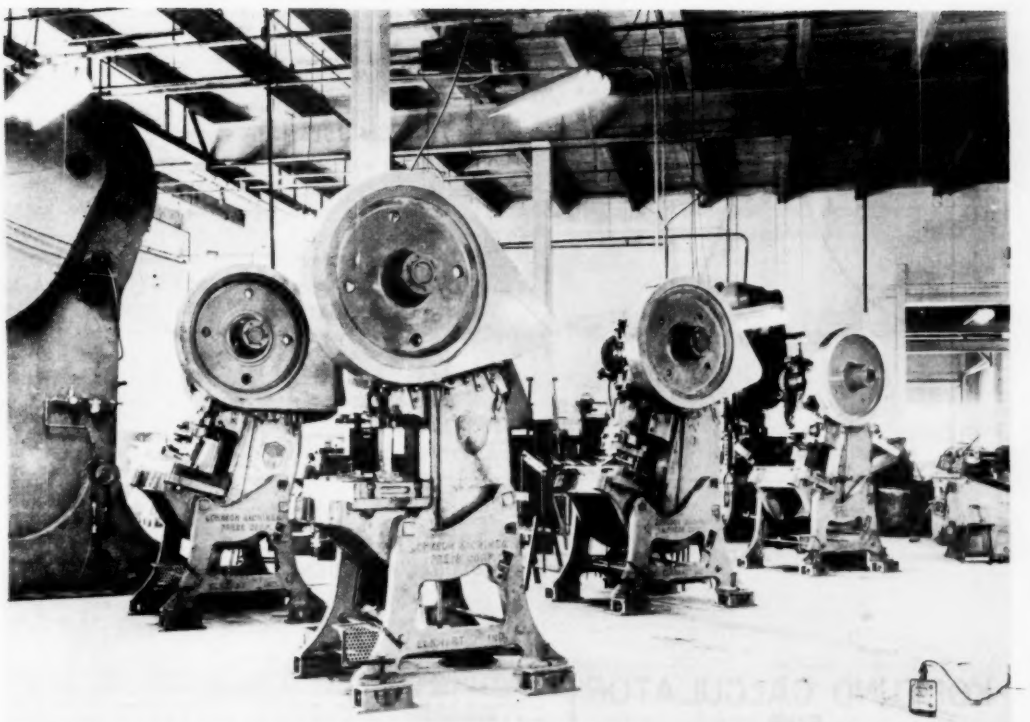


FIGURE #3. Typical punch press installation on spring Isolators which eliminated bolting to floor, permitted fast press re-arrangement for new production schedules and made it possible to greatly increase the press speeds for greater production by eliminating shock transmission to neighboring buildings.

FIGURE #4. One of two precision boring machines installed side-by-side on a weak upper floor. Shock transmitted from one machine to another caused intermittent skips and gouges. One machine had to be kept idle until both were mounted on the spring Isolators as shown. Now they operate together and turn out perfect work.

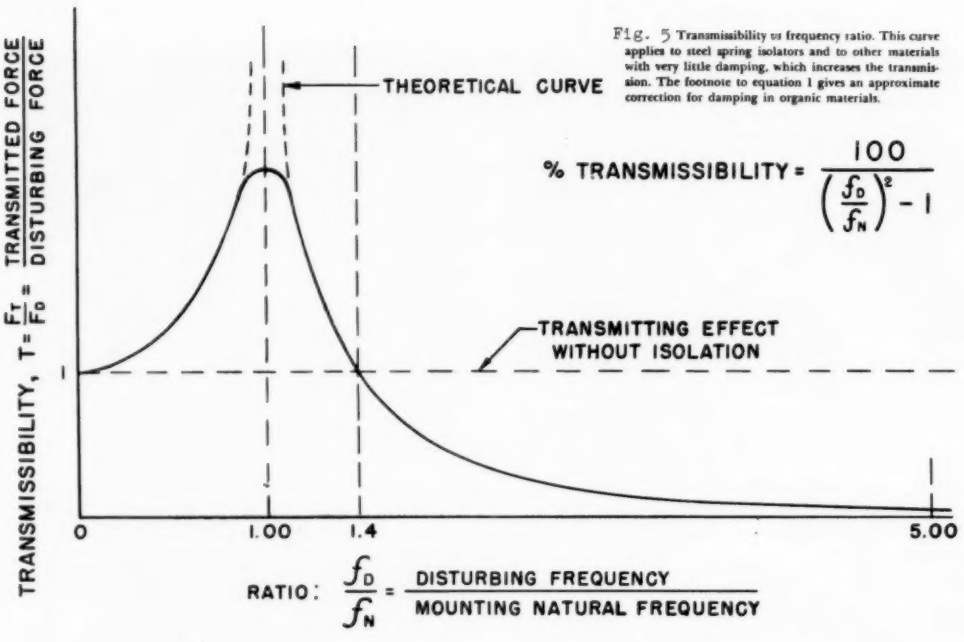


Fig. 5 Transmissibility vs frequency ratio. This curve applies to steel spring isolators and to other materials with very little damping, which increases the transmission. The footnote to equation 1 gives an approximate correction for damping in organic materials.

FIGURE 6

KORFUND CALCULATOR FOR VIBRATION ISOLATION

THE KORFUND CO., INC.
48-15 32ND PL. LONG ISLAND CITY 1, N.Y.

Here are typical problems which can be solved with this calculator

NATURAL FREQUENCY AND SPRING DEFLECTION — What natural frequency and spring deflection are required to isolate a disturbing frequency of 600 CPM with a transmissibility of 10%?

Answer: Vertical line from 600 on f_D scale intersects 10% transmissibility diagonal line at A. Horizontal line from A intersects f_N scale at 180 CPM and δ scale at 1.1" deflection.

SPRING CONSTANT — What spring constant is required to give a deflection of 1.1" for a load of 300 lbs.?

Answer: Horizontal line from 1.1" on δ scale intersects 300 lbs. weight diagonal line at B. Vertical line from B intersects K scale at 280 LBS. PER INCH.

SPRING DEFLECTION AND NATURAL FREQUENCY — What deflection and natural frequency are obtained with a 300 lb. load on a spring whose constant is 280 lbs. per inch?

Answer: Vertical line from 280 on K scale intersects 300 lbs. weight diagonal line at B. Horizontal line from B intersects δ scale at 1.1" deflection and f_N scale at 180 CPM.

TRANSMISSIBILITY — What is the transmissibility of a system having a natural frequency of 180 CPM and being disturbed by vibrations of 600 CPM frequency?

Answer: Vertical line from 600 on f_D scale, and horizontal line from 180 on f_N scale intersects at A on 10% transmissibility diagonal scale

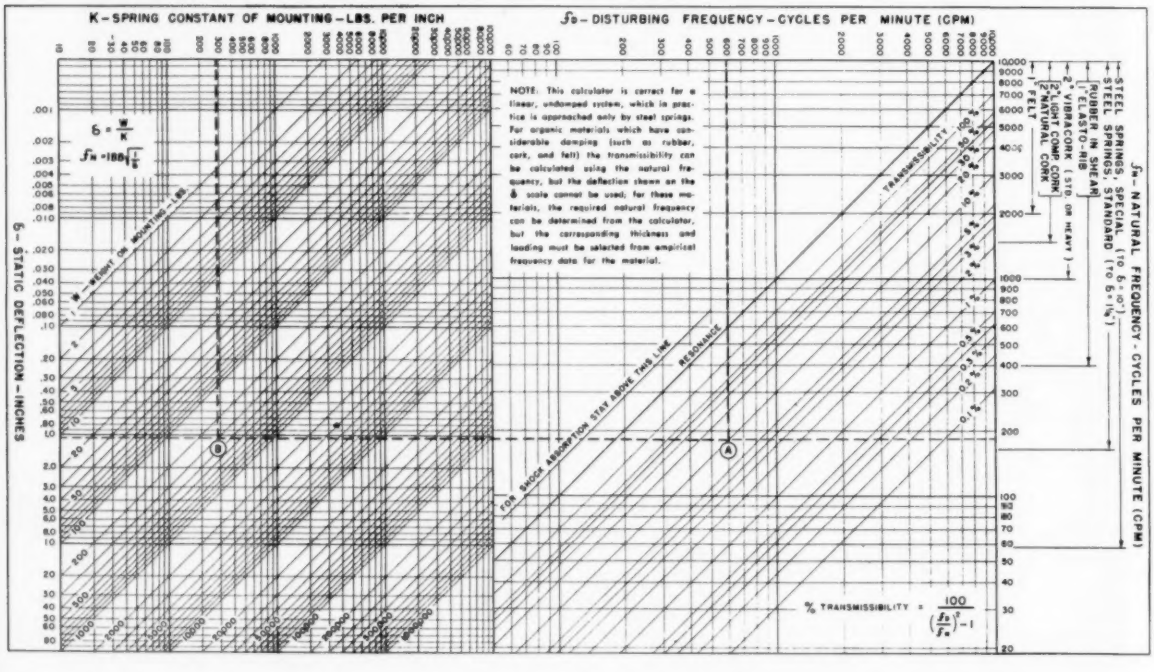

K – SPRING CONSTANT OF MOUNTING – LBS. PER INCH
fD – DISTURBING FREQUENCY – CYCLES PER MINUTE (CPM)
δ – STATIC DEFLECTION – INCHES
fN – NATURAL FREQUENCY – CYCLES PER MINUTE (CPM)
δ = W/K
fN = 188√(1/δ)
W = WEIGHT ON MOUNTING – LBS.
NOTE: This calculator is correct for a linear, undamped system, which in practice is approached only by steel springs. For organic materials which have considerable damping (such as rubber, cork, and felt) the transmissibility can be calculated using the natural frequency, but the deflection shown on the δ scale cannot be used; for these materials, the required natural frequency can be determined from the calculator, but the corresponding thickness and loading must be selected from empirical frequency data for the material.
FOR SHOCK ABSORPTION STAY ABOVE THIS LINE
RESONANCE
TRANSMISSIBILITY
100%
50%
40%
30%
20%
10%
6%
4%
3%
2%
1%
0.5%
0.3%
0.1%
% TRANSMISSIBILITY = 100 / ((fD/fN)² − 1)
FELT
2" NATURAL CORK
2" NEOPRENE COMP. CORK
RUBBER IN SHEAR (ELASTO-PAD STD. OR HEAVY)
STEEL SPRINGS; SPECIAL (TO δ = 0")
STEEL SPRINGS; STANDARD (TO δ = ¼")

FIG. 7 Force transmitted through shock mountings. The graph shows the load deflection curve for a typical steel spring and also for two stiffer mounting materials, such as rubber in shear and rubber in compression. Steel spring mountings for shock applications are selected to give a static deflection of at least 1/2 in. compared to 1/16 in. to 1/8 in. for other isolating materials. The shaded portions of the graph represent equal amounts of shock energy delivered by the punch press or hammer to each type isolation material initially subjected to the same static load (P_0). The steel springs deflect more and transmit much less force (P_1) to the subbase than is transmitted through the more rigid materials (P_2,P_3).

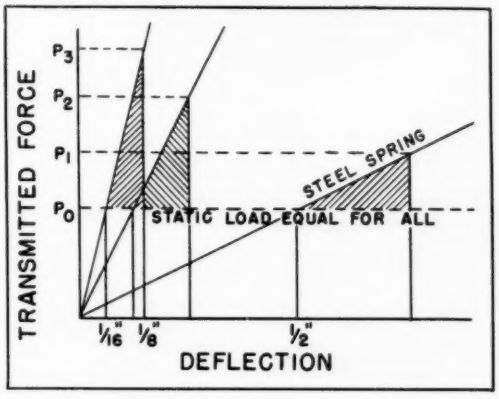
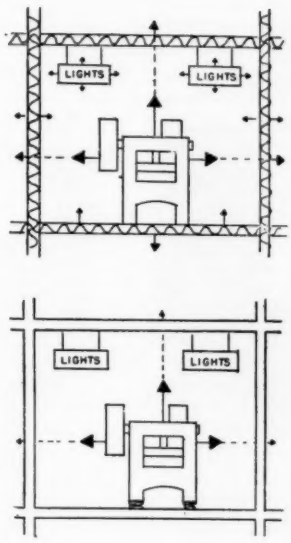
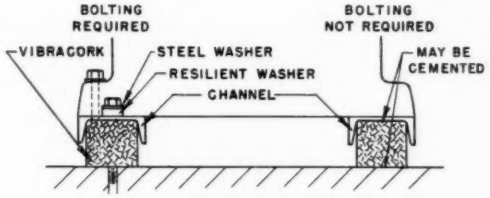
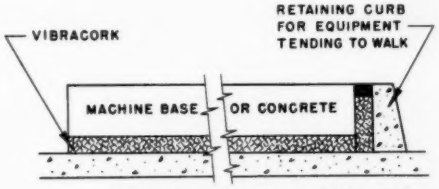


FIG. 8 Solidly mounted press at left transmits shock and high-frequency noise into the floor. The shock causes floors, walls, and lights to vibrate and act as secondary noise sources, in addition to the normal airborne noise transmitted from the press. With shock-mounted press at right, all structural vibration and noise transmission is stopped and secondary noise sources are eliminated.

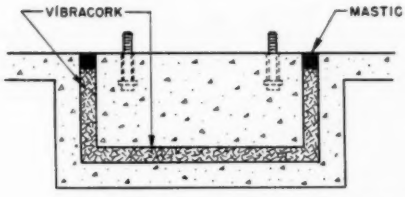




USING CHANNELS TO APPLY LOAD TO VIBRACORK FOR LIGHT MACHINERY



CONTINUOUS LAYER OF VIBRACORK FOR HEAVY MACHINERY AND CONCRETE FOUNDATIONS ABOVE FLOOR LINE



VIBRACORK FOR ISOLATION OF EQUIPMENT ON CONCRETE FOUNDATION BELOW FLOOR LINE

FIG. 9 Typical cork arrangements. Machinery-isolation cork is usually made in three densities for loadings from 1000 to 8000 lbs per ft^2. Standard sheet size is 12 in. by 36 in. in 1-in., 2-in., and 3-in. thicknesses. Most frequent application is under concrete foundations.

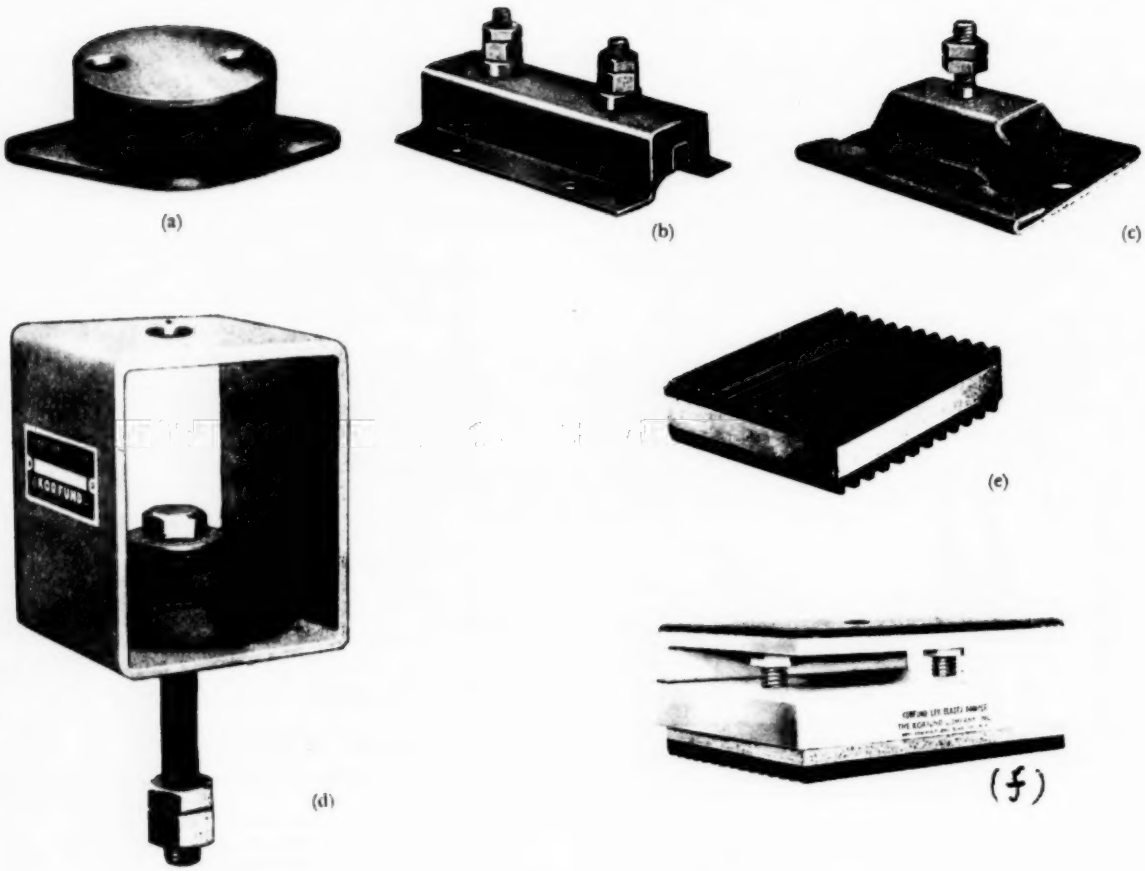


Fig. 10 Typical rubber and rubber-cork mountings. Load capacities of rubber mountings vary with their size, type, and rubber durometer. Approximate maximum deflection is 1/4 in., though some mountings can be stacked to increase the deflection. (a) Compression mountings support more weight per unit of area but require greater thickness of rubber to get the same deflection obtainable with a smaller volume of rubber when loaded in shear. (b) Pure shear mountings must not be overloaded, or the rubber-to-metal bond may fail. (c) Combination compression and shear mountings are more durable than pure shear mountings if overloaded. (d) Rubber-in-shear hangers for suspended equipment and piping. (e) Rubber-cork mountings combine characteristics of these two materials, provide non-skid surface which eliminates bolting machines down. (f) Rubber-cork mounting with built-in leveling screw.

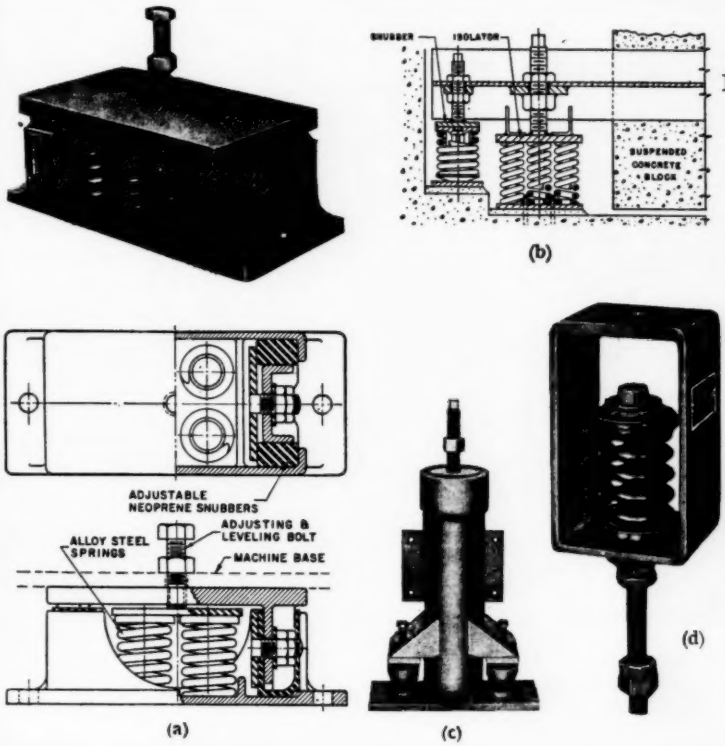
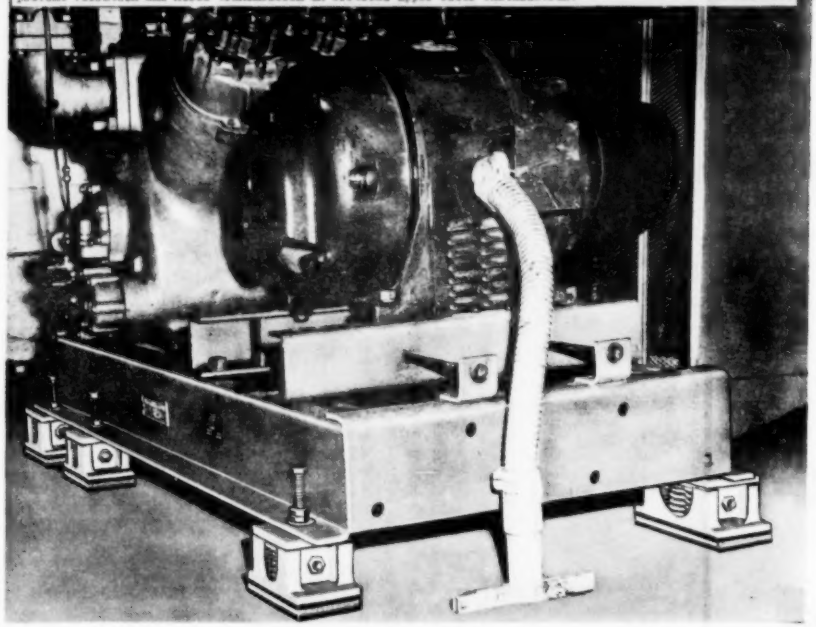


Fig. 11 Typical steel spring mountings. (a) Standard units of this type provide highly efficient isolation for most machines. Different sized housings accommodate from one to sixteen springs carrying loads from 50 to 23 000 lbs with spring deflections up to 1¼ in. (b) Heavy-duty isolator to support machines on concrete foundations or structural-steel chassis. Load range: 3000 to 35 000 lbs with standard deflections up to 1½ in. Mechanical friction-type snubber shown. (c) Long spring isolators for deflection up to 10 in. Load range: 50 to 20 000 lbs per isolator. Note separate adjustable snubbers at sides of isolator. When isolators shown in a, b, and c are used on jobs where high-frequency noise transmission is a problem, separate rubber sound pads are used between the bottom of the isolator and the floor. (d) Spring hangers for suspended equipment at piping. Load range: 20 lbs to 4000 lbs with standard deflections up to 1½ in. Hanger contains sound insulation washer to prevent high-frequency noise transmission.

FIGURE #12. Typical air conditioning compressor mounted on steel spring Isolators with rubber sound pads to prevent vibration and noise transmission on critical upper floor installation.



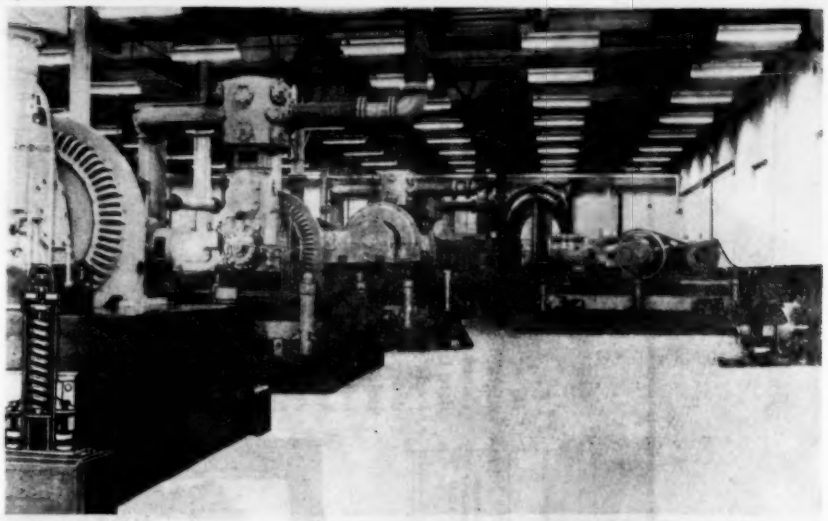


Figure #14. Effective spring isolation for fifteen of these large machines permitted installation on an upper mezzanine floor which would otherwise have been impossible. Large unbalanced forces in compressors and vacuum pumps of the types illustrated require heavy concrete foundations to minimize the movement. Note the use of flexible piping connections.

Figure #13. Effective vibration isolation permits installation of processing equipment such as this vibrating screen high in the building without special foundations or structural reinforcement for gravity [illegible] materials down through the piping.

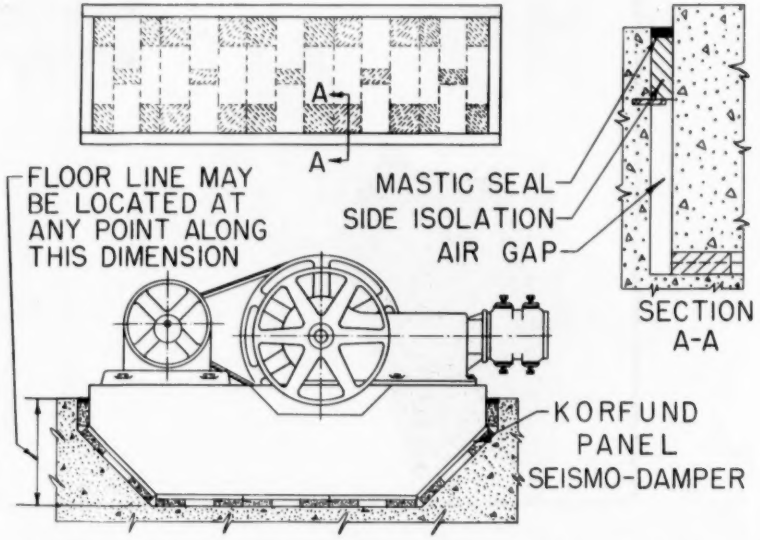


Figure #15. For non-critical locations in basements and ground floors, horizontal compressors and vacuum pumps can be installed on foundations with sloped ends with cork isolation. Cork blocks are cemented to the underside of plywood panels with the area and spacing of the cork varied to obtain optimum loading on the isolation material. For critical installations, spring-isolated foundations are required as shown in Figure #14.

FIGURE #16. The spring mountings shown permitted installation of two of these 300 ton centrifugal refrigeration machines in a penthouse on the roof of the building. All other air conditioning mechanical equipment was similarly mounted in the penthouse, providing operating economies and freeing the basement for valuable storage and storage space.

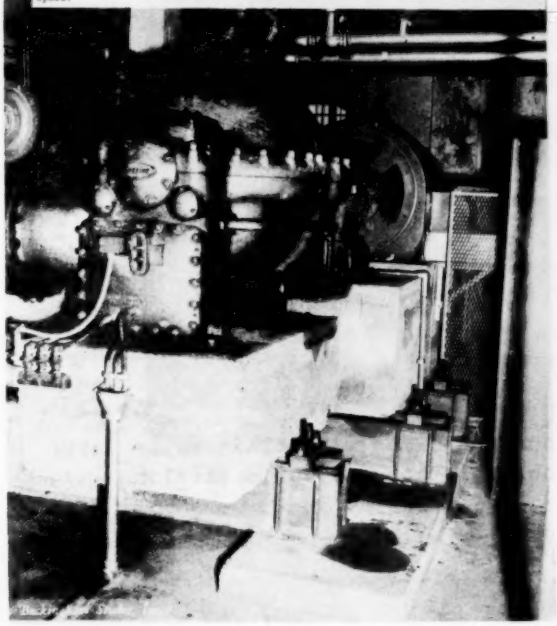
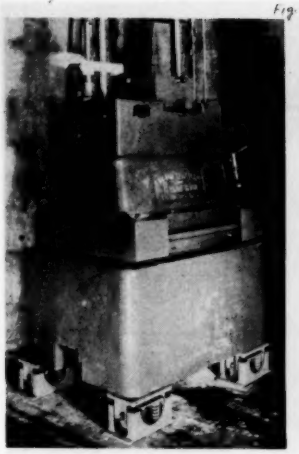
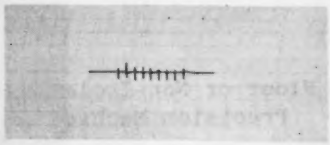


Fig 18



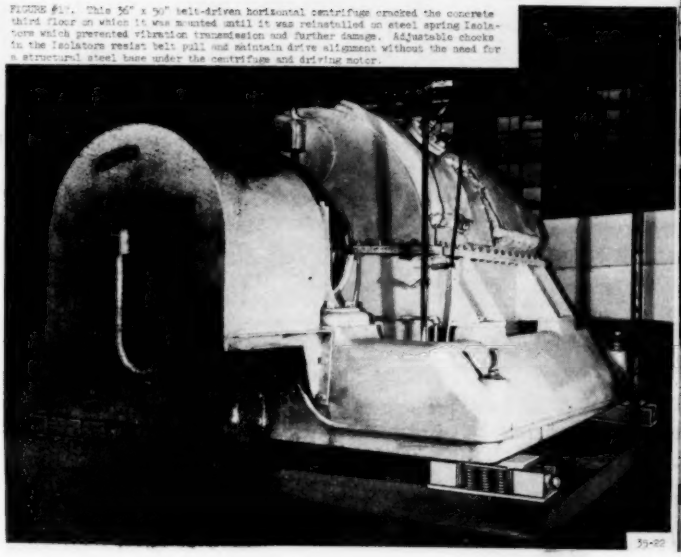
THE HIGH EFFICIENCY ISOLATION FOR THIS HAMMER PROVIDED BY KORFUND VIBRO-ISOLATORS IS DEMONSTRATED BY THESE OSCILLOGRAPH RECORDINGS SHOWING THE DISTURBANCES TRANSMITTED FROM THE ISOLATED HAMMER [ABOVE] COMPARED WITH THE DISTURBANCE CAUSED BY A HAND-SLAP ON THE FLOOR (BELOW).



21,000# PNEUMATIC LIFT, GRAVITY DROP HAMMER WITH 400# FALLING RAM. HAMMER IS PLACED DIRECTLY ON KORFUND ISOLATORS. NO ANCHORING TO FLOOR, NO CONCRETE FOUNDATION IS NEEDED.

FIGURE #19. Rubber mountings under these milling machines prevent vibration transmission to other equipment and eliminate bolting to the floor so that the machines can be quickly re-arranged as production lines change. Built-in leveling screws eliminate the need for shims.

FIGURE #17. This 36" x 96" belt-driven horizontal centrifuge cracked the concrete third floor on which it was mounted until it was reinstalled on steel spring Isolators which prevented vibration transmission and further damage. Adjustable chocks in the Isolators resist belt pull and maintain drive alignment without the need for a structural steel base under the centrifuge and driving motor.



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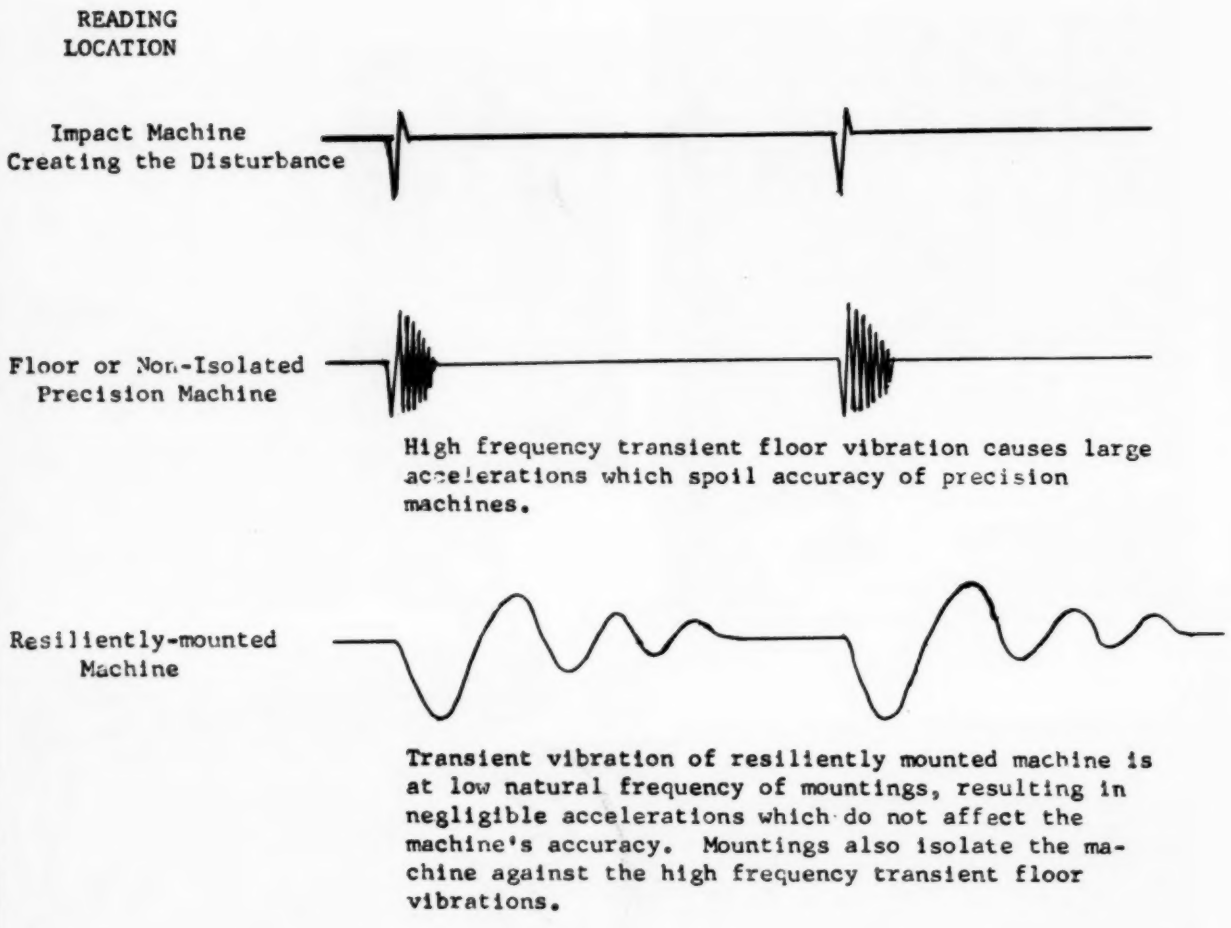

READING
LOCATION
Impact Machine
Creating the Disturbance
Floor or Non-Isolated
Precision Machine
High frequency transient floor vibration causes large accelerations which spoil accuracy of precision machines.
Resiliently-mounted
Machine
Transient vibration of resiliently mounted machine is at low natural frequency of mountings, resulting in negligible accelerations which do not affect the machine's accuracy. Mountings also isolate the machine against the high frequency transient floor vibrations.

Figure #20. As explained in the text, these graphs show how resilient mountings under precision machines protect them against impact shock and high frequency transient floor vibration created by such shock.

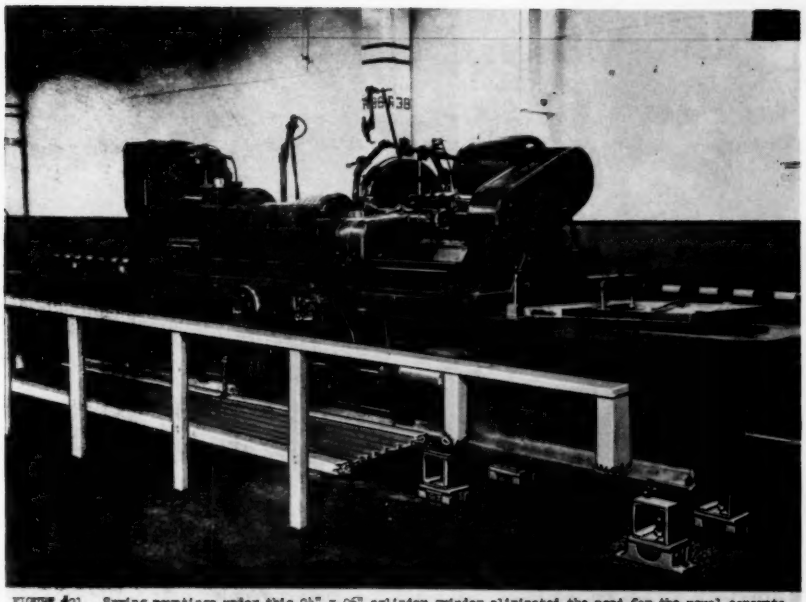
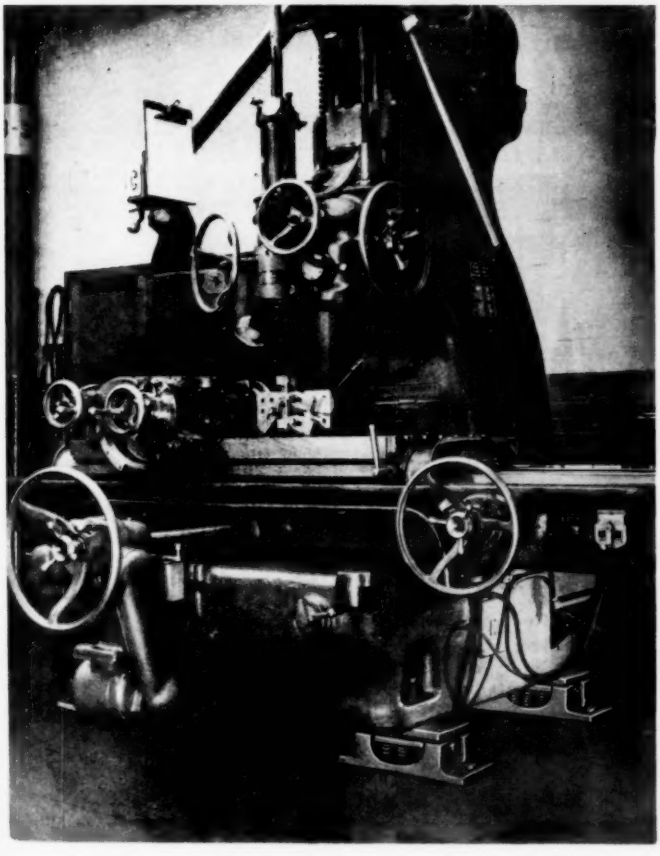


FIGURE #21. Spring mountings under this 24" x 96" cylinder grinder eliminated the need for the usual concrete foundation and protected the machine against external vibration from trucks and other equipment.

FIGURE #22 Vibration from engine test rooms and passing trucks interferred with the accuracy of this precision jig borer until it was mounted on steel spring Isolators which solved the problem.



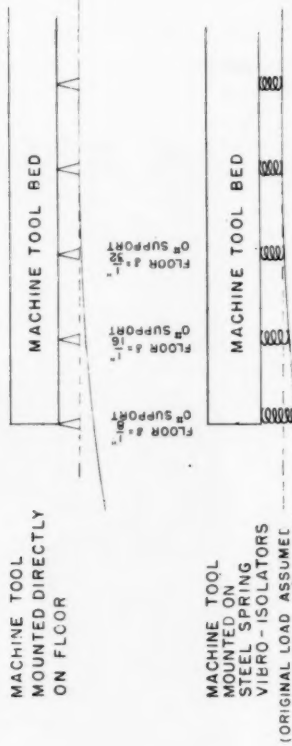


FIGURE #23. Diagrams show why frequently machine tools installed on weak upper floors without resilient mountings distort and cause work rejects when passing trucks and the varying loads cause deflection of the floor under the machine. In contrast, resilient spring mountings provide nearly undiminished support for the machine under the same conditions.

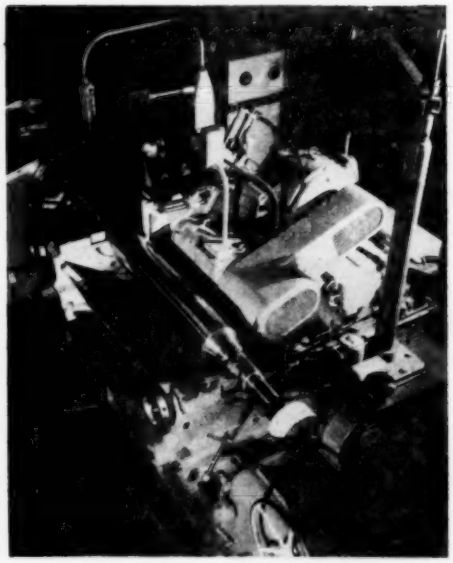
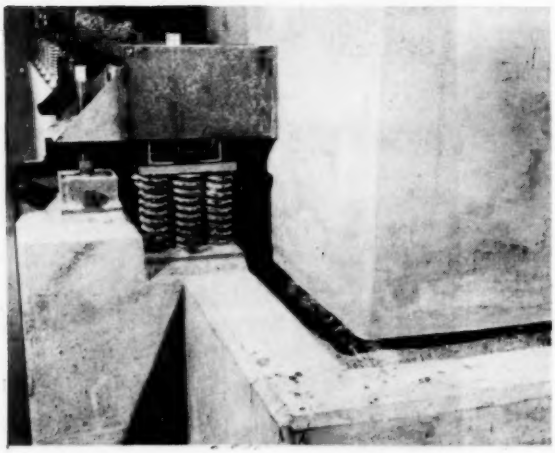
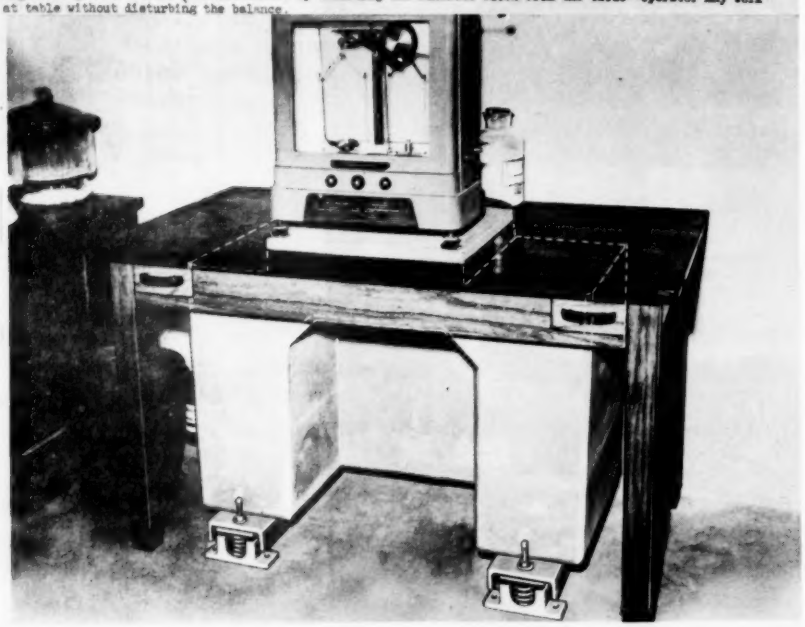


FIGURE #24. This 75 ton roll grinder operates to tolerances of ±0.0002" with a finish of 1.4 mu in.rms., on rolls up to 36" diameter and 192" long. A spring isolated foundation weighing 235 tons protects the extreme accuracy of this machine against vibration and shock from passing trucks and the aluminum foil mill machinery.



Corner detail of foundation suspension system, showing a 9-spring isolator and snubber assembly. 28 spring and 4 snubber assemblies were used to "float" this grinder foundation.

FIGURE #25. Korfund Steel Spring Vibro-Isolators protect this delicate analytical balance from vibration and disturbances caused by crushing and shaking equipment in this large processing plant. Phantom view shows how highest degree of accuracy is maintained by isolating the concrete block from the table--operator may work at table without disturbing the balance.



DIFFERENTIAL PROFIT CONTROL
(A Simplified Method of Overall Profit Optimization)

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An industrial enterprise must fulfill certain social obligations. It further must be careful not to endanger its long range stability and prosperity through a policy of short run gain. Subject to these considerations, however, the maximization of profit is the primary goal of managerial policies.

During the past few years increasing attention has been given to the advantages of using mathematical concepts for the purpose of profit maximization. New methods of programming have been proposed. Many of them require such involved computations that they would be totally unrealistic if it was not for the fact that new tools have been made available for performing such computations. In this respect like in many other fields, the development of electronic computers has opened entirely new horizons.

Many of you are fully conversant with the new methods that have been proposed. Some of us may be reluctant to spend too much time in learning how to master them because, after all, they are rather complex. This is true even when they are called by encouraging names, such as the "simplex method", for instance. All of us, in any case, are very much interested in the great potentialities of these new methods of computing and programming. They are very promising in terms of profit maximization and many have already proved their value beyond doubt.

Up to now it seems that the mathematical methods that have received the greatest attention, have been, as a whole, directed toward the maximization of the profit related to specific operations. By this we mean, for instance, the determination of the most economical production lot size, or the determination of the most economical method of delivery of goods from warehouses spread all over the country, or the determination of the most economical scheduling in a given plant or part of a plant, etc.

Obviously the solution of such specific problems deserves full attention. The way to maximize total profit is, in good logic, to start by maximizing profit for each or some of the specific factors which influence total profit. At the same time, it is not always true that the summation of specific maximizations effected independently from each other will necessarily and automatically result in total profit maximization. After all, the industrial enterprise, in spite of its great complexity, constitutes a single entity. This means that no specific step can be taken without somehow involving the whole enterprise, directly or indirectly. Maximization of a specific element of profit may well, in final analysis, be overcompensated by a substantial decrease of profit somewhere else. The far-reaching implications of any specific decision are not always easy to foresee.

There is another fundamental reason for basing profit maximization upon an overall picture. It is the fact that every specific decision is always, directly or indirectly, made possible by high policy decisions. These, in turn, are, by definition, based upon an evaluation of the overall picture of the whole situation.

To illustrate-- on April 15, 1956, some steps are taken in Dept. 37 of the XYZ Co. These steps will result in substantial cost reduction in the manufacturing of item 123. This is a case of specific profit maximization. But the steps that have been taken were made possible only because, among other factors, Mr. X., the industrial engineer who recommended them, had been hired following the high policy decision to create an industrial engineering department. This high policy decision taken in 1955 by the Board of Directors involved an increase of total overhead before it resulted in specific profit maximization. It was a necessary prerequisite to the specific cost reduction arrived at in Dept. 37 on April 15, 1956, with relation to the manufacture of item 123.

This illustrates the fact that profit maximization requires that attention be given to the "synthetic approach" as well as to the "analytic approach." Actually, the two approaches complement each other.

This fact is, of course, fully recognized in industry. This is why profit control is traditionally based upon the simultaneous use of cost accounting, i.e., the "analytic approach" and general accounting, i.e., the "synthetic approach."

As previously mentioned, it seems that most of the new concepts which are using mathematical methods for the purpose of profit maximization relate to specific operations. They follow the "analytic approach". As such they can be considered as a sort of modernization of cost accounting.

There seems to be also an opportunity of stimulating the modernization of general accounting by following the "synthetic approach" in using mathematical concepts to maximize total profit.

The method to be now discussed is intended to be a step in this direction. It is based upon difference computations and for this reason can be called a method of <u>differential profit control</u>.

Considering the cost structure of an industrial enterprise as a whole, at a given time, and operating under given conditions, it is found that the costs can be classified in two groups: variable and constant costs. The variable costs vary directly with the volume of production. Such are the cost of material, the cost of direct labor, for instance. The constant costs, despite their designation, do vary. But their variation is not directly related to a change in the production level.

The break-even chart, first presented by Walter Rautenstrauch and now being used throughout industry, is prepared on the basis of this fundamental classification of cost. It provides a graphical representation of the cost to sales relationship for the enterprise as a whole or one of its subdivisions.

The method of differential profit control to be now discussed is an attempt to provide a greater flexibility in the preparation and the use of the break-even chart. Essentially it amounts to the preparation of what could be called a "differential break-even chart."

To illustrate the principles involved, let us take the ABC Co. For the year 1955 the profit and loss statement of the ABC Co. shows the following results (in $ millions):

Total sales		$15.0
Cost of goods sold	$10.0	
Selling expense	2.0	
Administrative expense	1.5	
Total expense		13.5
Net profit before taxes		$ 1.5

Let us say that the analysis of cost provides the following figures:

Labor	$ 3.0
Material	5.0
Other variable costs	2.0
Total variable	$10.0
Total constant	3.5
Total cost	$13.5

Figure 1 shows the break-even chart obtained in plotting sales in abscissa and cost in ordinate using the same scale.

The trend expense to sales is defined by the equation:

$$y = a + b\,x$$

where

y = total expense
x = total sales
a = constant expense

$b = \frac{V}{s}$ = ratio variable expense to sales

In this case

$$y = 3.5 + \frac{10}{15}\,x$$

This equation is valid only within accertain range of variation of the volume of production and only as long as the conditions of operation remain unchanged.

If the sales of the ABC Co. increase from 15 to 20 millions, the variable expense V is still defined by the equation:

$$V = bx = \frac{10}{15}\,x = \frac{10}{15}\,20$$

but certain elements of constant expense, the supervisory expense, for instance, and a few others, will have to be increased. If their total increase was to be .3 then the equation

$$y = 3.5 + \frac{10}{15}\,x$$

becomes

$$y = 3.8 + \frac{10}{15}\,x$$

If in addition some progresses are made in methods and processes which increase labor efficiency by 20% (at 15 M. of sales, labor cost is 3 M) then the slope of the trend decreases. The equation becomes:

$$y = 3.8 + \frac{9.4}{15} x$$

If there should be a change in the sales mixture, the slope of the trend is further modified.

Do these considerations affect the usefulness of the break-even chart? Certainly not, as well proved by its increasing adoption in industry. Its usefulness results essentially from two characteristics:

1. The chart provides a linear equation which defines the cost to sales relationship within a certain range of variation of the volume of production and which remains valid as long as the conditions of operation remain unchanged.

2. When this range of variation of the volume of production is exceeded and/or when the conditions of operation change, the chart provides the basis from which the impact of a change can be measured.

It is now proposed to take full advantage of these two characteristics by combining them into one single mathematical model which will provide both the linear equation that defines the cost to sales relationship and the structure within which computations can be made in a comparatively simple manner to measure the impact of a change. This mathematical model is the equation:

$$y = (a + \Delta_a) + (b + \Delta_b) x$$

where

y = cost
x = sales
$a = \sum_{i=1}^{N_o} a_i$

a_i = elements of constant costs that have been recorded at the time T_o of the original analysis.

$\Delta a = \sum_{i=1}^{N_1} \Delta a_i$

Δa_i = either the difference due to a change in the original elements of constant cost (a_i to a_{N_o}) or

the value of additional elements of constant costs that have been recorded at the time T_1 of the subsequent cost analysis (a_{N_o+1} to a_{N_1})

$$b = \sum_{i=1}^{N_o} b_i \qquad b_i = \frac{V_i}{S_o}$$ = ratio of elements of variable costs to sales as recorded at the time T_o of the original cost analysis.

$$\Delta b = \sum_{i=1}^{N_1} \Delta b_i$$ Δb_i = either the difference due to a change in the original ratio of elements of variable costs to sales as recorded at the time T_o of the original analysis (b_1 to b_{N_o}) or the value of the ratio to sales of additional elements of variable costs that have been recorded at the time T_1 of the subsequent cost analysis (b_{N_o+1} to b_{N_1})

Later on, as subsequent analyses are made, at the time T_2, T_3 .....T_n, then:

$$\Delta a = \sum_{i=1}^{N_n} \Delta a_i$$

$$\Delta b = \sum_{i=1}^{N_n} \Delta b_i$$

This approach simplifies the computations needed for profit control as will now be shown. If we consider the equation of differential profit control

$$y = (a + \Delta_a) + (b + \Delta_b) X$$

we see that it includes two groups of factors.

First group includes the two basic factors "a" and "b".

The determination of "a" and "b" requires a detailed analysis of the expense accounts, which must be classified either as constant or as variable. It sometimes requires breaking down an account into a variable and a constant section. It generally requires rather lengthy computations.[1] By following the method now proposed it will still be necessary to perform these computations at the time of the original analysis but it will be possible to avoid repeating them. At the time T_1----T_n of subsequent analysis, computations, as a rule, will be limited to the second group.

Second group includes the difference factors Δ_a and Δ_b which will be computed as often as necessary. The control of Δ_a is based upon the fact that a change in the constant expense by definition requires managerial action. A change in supervisory expense, for instance, may be related to the volume of sales but it does require specific action. In fact, in a well budgeted company, such changes call for an adjustment in the budget. The computation of Δ_a can therefore be based upon the fact that such changes are recorded. They can be detected as a matter of routine of control. Their impact can be computed if and when they occur.

The same is true for most of the changes influencing Δ_b.

A mere change in the volume of production may occur so often and so irregularly that it would escape routine recording. The fact is, however, that such a change affects only the variable expense, not its ratio to sales. Hence it does not influence Δ_b.

A change in the conditions of operations, such as wage increase or decrease, material price fluctuation, improvement in labor efficiency, affects the ratio of variable expense to sales. It, therefore, must be computed as part of Δ_b. As a rule, however, it can be said, that such changes require specific managerial action. They are recorded. They can be detected as a matter of routine of control in the same manner as changes affecting Δ_a. Their impact can be computed if and when they occur.

These remarks also apply to the quantitative evaluation of the impact of a change in the sales mixture. This is, as you well know, a matter that has received increasing attention in recent years. It is thought that the method of differential profit control can greatly simplify the problem of sales mixture control.

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1. See R. Villers, The Dynamics of Industrial Management, (Funk & Wagnalls, 1954) p. 333.

All this can best be illustrated by using some precise figures. Let us return to the case of the ABC Co. previously mentioned. Cost figures for 1955 are:

Labor	$ 3.0 (in millions)
Material	5.0
Other variable cost	2.0
Total variable	$10.0
Total constant	3.5
Total Cost	$13.5

Total sales for the year 1955 were 15.0

An analysis of the sales mixture based upon a classification of items according to the percentage of direct profit per dollar of sales (1) shows the following results for the year 1955 (data is for illustration only):

Direct Profit Groups	Sales (in $)	Sales (in %)	Weighted Average
30	1.5	10	300
35	3.0	20	700
40	4.5	30	1200
45	1.5	10	450
50	4.5	30	1500
Total	15.0	100	41.50

The equation of differential profit control is:

$$Y_o = (3.5 + \Delta_a) + \left(\frac{10}{15} + \Delta_b\right) X$$

It is upon this equation that the break-even chart shown in Fig. 1 was based. This equation is valid for any volume X of total sales, as long as the conditions of operations remain characterized by

constant expense	$a = 3.5$
ratio variable expense to sales	$b = \frac{10}{15}$

(1) For an extensive discussion of this method, see R. Villers The Dynamics of Industrial Management, Chapter 13, and David S. Fields, "Sales Mixture Control" in The Comptroller, May, 1955.

During the first quarter 1956, these conditions have changed. It is expected that the new conditions will prevail throughout 1956. Computations will then be made on a yearly basis. Otherwise provision should be made for seasonal adjustment or reduction on a monthly basis.

Changes are as follows:

I - Affecting the Constant Expense

1. A new machine has been bought, raising depreciation by

$$\Delta a_1 = .5$$

2. Supervisory expense was increased, because of an expected increase in production, by

$$\Delta a_2 = .003$$

3. The Board of Directors has increased advertising budget by

$$\Delta a_3 = .01$$

4. Money has been borrowed creating a new item of constant expense, interest payment:

$$\Delta a_{50} = .25$$

II - Affecting the Variable Expense

1. An incentive plan has resulted in an increase in labor efficiency, providing

$$\Delta b_1 = -\frac{2}{100}$$

2. The new machine results in reduction in labor costs, providing

$$\Delta b_2 = -\frac{15}{100}$$

3. The new machine results in reduction in waste of material providing

$$\Delta b_3 = -\frac{8}{100}$$

Assuming for the time being that all other conditions of operation remain constant, including the sales mixture, then in the equation:

$$Y_o = (3.5 + \Delta_a) + (\frac{10}{15} + \Delta_b) \; X$$

$$\Delta_a = \Delta_{a_1} + \Delta_{a_2} + \Delta_{a_3} + \Delta_{a_{50}}$$

$$= .5 + .003 + .01 + .25$$

$$= .73$$

$$\Delta_b = \Delta_{b_1} + \Delta_{b_2} + \Delta_{b_3}$$

$$= -\frac{2}{100} - \frac{15}{100} - \frac{8}{100}$$

$$= -\frac{25}{100}$$

The equation

$$Y_o = (3.5 + \Delta_a) + (\frac{10}{15} + \Delta_b) \; X$$

becomes

$$Y_1 = (4.263 + \Delta_a) + (\frac{50}{100} + \Delta_b) \; X$$

At 15 millions of sales, the figure reached in 1955, profit was:

$$P_o = 1.5 \text{ since } P_o = X_o - Y_o = X_o - [3.5 + \frac{10}{15} X_o] \text{ and } X_o = 15$$

At the same volume of 15 million under the new conditions of operations, profit would be

$$P_1 = 3.237 \text{ since } P_1 = X_1 - Y_1 = X_1 - [4.263 + \frac{50}{100} X_1] \text{ and } X_1 = 15$$

Profit has more than doubled because of the change in policy.

This raises, however, immediate questions such as:

--What if sales decrease to 13 millions?

--What if we reduce our prices?

--What if this reduction in prices raises sales again?

--What if the sales mixture changes?

All these and many similar questions arise constantly at meetings where high policy decisions are taken, Board of Directors or Executive Committee meetings.

Such questions are better answered and a comprehensive view of the whole situation is presented in a more effective manner at committee meetings if the equation of differential profit control is used in connection with the break-even chart and the sales mixture chart.

Figure 2 shows the original trend T_o as it was shown in Figure 1. It also shows the trend T_1 as determined on the basis of the above difference computations.

T_o and T_1 cross each other at the limit point L. The volume of sales indicated by the abscissa of L can also be computed algebraically. It is X_1 so that

$$Y_o = Y_1$$

or $$3.5 + \frac{10X_1}{15} = 4.263 + \frac{50X_1}{100}$$

$$\frac{2.5}{15} X_1 = 7.63$$

$$X_1 = 4.58$$

Above this volume, T_1 is more favorable than T_o. The reverse is true below this volume. The determination of the limit point L defines the volume limit for total profit optimization.

By using the equation for differential profit control and projecting it on a break-even chart, it will always be possible to evaluate the relative merits of two or more solutions in relation to the volume of total sales that each solution is expected to provide. This provides a basis upon which to base high policy decisions tending toward profit optimization.

It now remains to discuss a last element of complexity, the change in the sales mixture.

Returning to T_o, the original trend defining the ABC Co.'s break-even chart,

$$Y_o = (3.5 + \Delta_a) + (\frac{10}{15} + \Delta_b) X$$

We found that

$$Y_1 = (4.263 + \Delta_a) + (\frac{50}{100} + \Delta_b) X$$

on the basis of the original sales mixture. Actually, however, an analysis of the sales mixture for the first quarter 1956 shows a change. The original pattern represented by the sales mixture chart shown in Fig. 3 (plain line) has now changed to the dotted line pattern.

What is the impact of the new sales mixture pattern upon the trend T_1 of the break-even chart? This is where the equation for differential profit control is most useful. The representation of the structure of the sales mixture requires the detailed analysis shown by the sales mixture chart and this is necessary for getting a picture of the market problems involved. But a simple relationship can be established between this analytic pattern and the synthetic trend of the break-even chart by noting that, from the point of view of total profit control, a sales mixture is characterized by its weighted average profit.

As seen above, the weighted average direct profit for the year 1955 of the ABC Co.'s sales mixture was

$$W_o = 41.50$$

The sales mixture for the first quarter 1956 (dotted line in the sales mixture chart Fig. 3) is as follows (Total sales for the quarter are 5 millions)

Direct Profit Group	Sales (in $)	Sales (in %)	Weighted Average
30	2.5	50	1500
35	1.5	30	1050
40	.5	10	400
45	.25	5	90
50	.25	5	100
	5.	100	31.40

The new sales mixture's weighted average profit is:

$$W_1 = 31.40$$

The difference in weighted average profit provides the Δ_b for the sales mixture change factor Δ_{b_m}

$$\Delta_{b_m} = \frac{41.50 - 31.40}{100} = \frac{10.10}{100}$$

The <u>decrease</u> in profit <u>increases</u> b by this amount.

To relate the sales mixture chart to the break-even chart, simply requires incorporating this difference in the equation of differential profit control. Thus, for the year 1956, the equation which, on the basis of an unchanged sales mixture was:

$$Y_1 = (4.263 + \Delta_a) + (\frac{50}{100} + \Delta_b) X$$

will, if the sales mixture alone changes, become:

$$Y_2 = 4.263 + \frac{60.10}{100} X$$

This equation is obtained by introducing

$$\Delta_a = o \text{ and } \Delta_b = \Delta_{bm} = \frac{10.10}{100}$$

so that

$$a = 4.263 \text{ and } b = \frac{50 + 10.10}{100} = \frac{60.10}{100}$$

The new trend is shown as T_2 in Fig. 2.

Profit computations show that at $15 millions of total sales, the profit was

$$P_o = 1.5$$

under the 1955 conditions of operations. Under the new conditions of operations it increases to

$$P_1 = 3.237$$

if the sales mixture remains unchanged, but remains at

$$P_2 = 1.722$$

if the sales mixture changes to the new pattern observed during the first quarter 1956.

It is obvious, however, that total sales will not remain permanently at the level of $15 millions. Profit control must take this into account. The great advantage of the break-even chart is to provide a dynamic graphical representation. It provides a control based upon the determination of trends (such as T_1, T_2 in Fig. 2) valid within a certain range of variation, rather than a control based upon a strictly defined volume of sales.

To Summarize

The method of differential profit control based upon the equation

$$Y = (a + \Delta_a) + (b + \Delta_b) X$$

is essentially intended to serve the following three purposes:

The first purpose is to provide a mathematical model within which computations can be made to take full advantage of the new tools of computation now available and of the new methods of linear programming related to specific profit optimization. This should be of help in measuring the relative value of alternatives when pursuing a policy of profit optimization.

The second purpose is to reconcile total sales control with sales mixture control by providing a quantitative relationship between the break-even chart and the sales mixture chart. This quantitative relationship is based upon a simple computation of differences between weighted averages of direct profit.

The third purpose is to introduce an element of flexibility in the use of the break-even chart, which has provided such a valuable tool of management.

It is thought that the methods of specific profit optimization that have been developed in recent years will, in the years to come, greatly reduce the cost of production in industry and thus bring to an even higher level our standards of living. The more we are able to bridge the gap between abstract mathematical concepts and actual practice of industrial management, the more we will accelerate this desirable improvement of industrial operations.

It is hoped that the method of differential profit control can contribute its share by making it possible to present to the industrial executive a simplified synthetic view of the increasingly complex picture of the industrial enterprise.

Because this overall picture is based upon the re-grouping of each specific element of cost, each broad problem can be discussed in terms of specific influential factors. Because each individual factor is related to all other factors within the structure of the equation of differential profit control, it is hoped that this method can help in reaching high policy decisions tending toward overall profit optimization in the conduct of industrial operations.

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Fig. 1

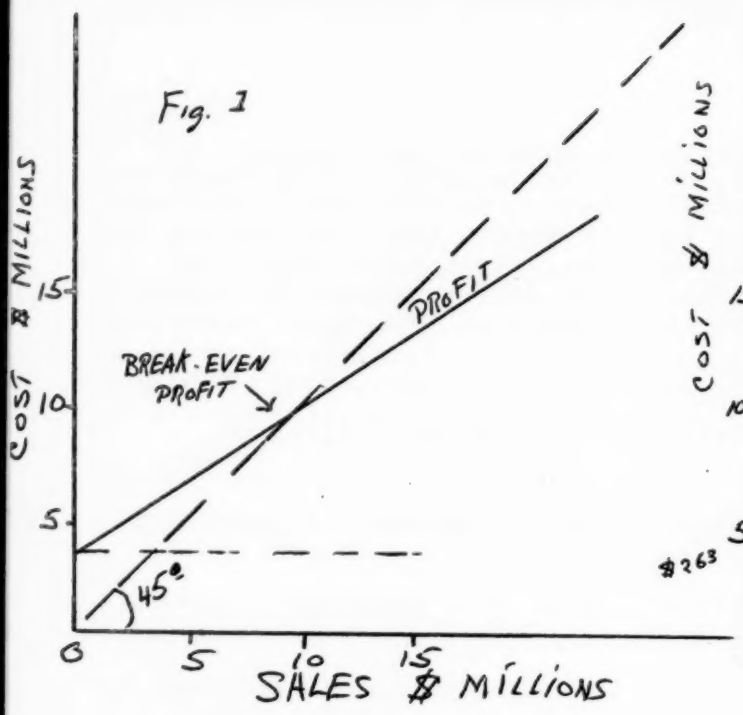


Fig 2

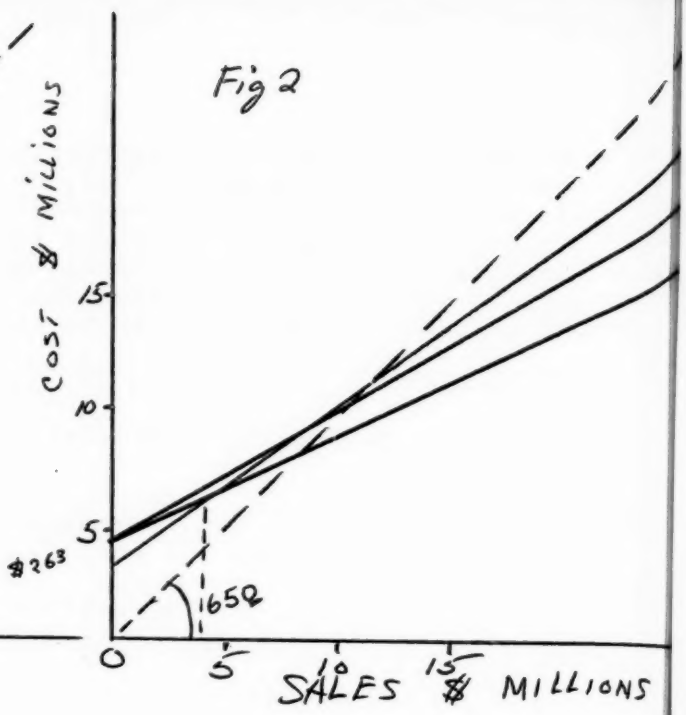
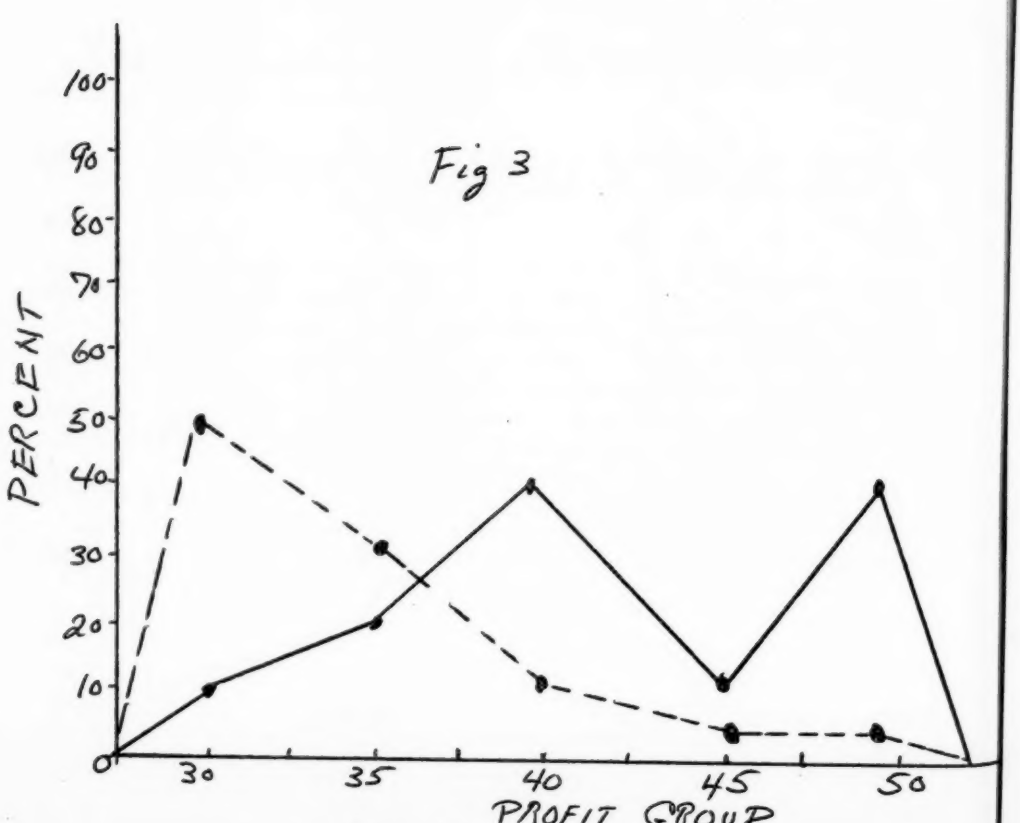


Fig 3



APPLICATIONS OF THE MONTE CARLO METHOD IN SYSTEMS ANALYSIS

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The Monte Carlo method has proved well suited for doing research in systems; and the Industrial Engineers - for reasons which I will try to bring out today - are among those best qualified to adapt and install the products of this method.

I plan to develop my topic through specific cases and by describing actual tools of the experimenter. First, however, we ought to define the terms we will be using.

By systems analysis I mean research and development in the total system represented by a business organization: this includes sub-systems like the accounting system, the scheduling system, the production-control system; or sub-sub-systems like the billing system or the system of expense account forms and records. Of course we will not be talking about strictly mechanical or electrical systems.

By the Monte Carlo method I mean the method of causing an experimental model of a system to act under random influences while observing and summarizing its behavior.

The Monte Carlo method strictly so called was developed during the war by John von Neumann, Stanislas Ulam, and others, for solving problems in nuclear physics. The general introduction of electronic digital computers, however, as we will discuss, has greatly expanded the range of applications of the method.

There is a question in my mind whether in systems analysis we should continue to use the term. The physicists may legitimately object to our doing so.

Possible alternatives are "operational simulation", which implies that we analyze the simulated operations of a system - or "operational gaming" which carries over the concepts of probabilistic war-gaming to the industrial sphere.

If these terms are not identical in connotation, they are closely allied and I will consider myself free to use all three of them.

The important thing is, that in principle these probabilistic methods of analysis are simple and experimental.

The class of industrial problems to which they are applicable seem to have two main characteristics, which the particular problem we are about to explore will show:

first, available mathematical theory does not suffice for a solution.

second, direct experimentation would be prohibitively costly in money or in time.

Now, as many of you know, Monte Carlo methods are usually linked with advanced computational aids. I suggest, however, that in setting up our industrial problem, we proceed as far as we can with ordinary methods of pencil, paper and desk calculator.

Suppose we look at this problem from management's point of view - or from the viewpoint of an analysis team in staff relationship to management - in a heavy process industry, say mining and milling, smelting, oil, chemicals, alloys or steel.

We are concerned primarily with a product at one of our company's plants - call it Product A - and our principal item of initial information is, that its sales curve has been seasonal with a peak in July and August.

Plant inventories have been erratic - sometimes embarrassingly high for long periods, at other times so low as to interfere with shipments.

The Operating Department wants a more stable production schedule at the plant. The Sales Department believes we could sell even more in the peak season if we could make the advance contractual commitments, so in short, the problem put up to our research team is to devise a level production scheme which will maximize profit without unduly increasing risk.

I am building up this background for you to describe and define the situations in which I believe these probabilistic research methods will find their industrial applications.

Now bear in mind, we are talking about a heavy industry example - three months production of Product A could tie up on the order of a million dollars. The basic idea, however, is plain enough -- produce in part for stock in the slack months, ship in part from stock in the peak months. Standard inventory theory, or similar straight-forward methods, would no doubt provide the answer for Product A if that were all we had to consider.

But it happens there are some complications - one of the main ones being another product at the plant, Product B.

Production of B is dependent on A, to some extent. That is, up to the first 6000 tons per month of A can be produced "free" - in other words without necessarily producing any B. Above that level one ton production of A entails one ton of B.

Of course, conversely, any production of B at all forces production of A.

Moreover, since the apparent density of B is double that of A and the same storage facilities at the plant are used for both, allocation of our storage will have to be planned with special care.

Parenthetically let me point out such a relationship could exist, for instance between caustic soda and chlorine at a plant with both electrolytic and ammonia soda facilities. You could get a certain quantity of caustic from the ammonia soda process without any chlorine, but to get more caustic you would have to use the electrolytic plant and that would entail producing chlorine. Do not try to identify my hypothetical A and B with caustic and chlorine, they differ in other factors. But I mention this just to bring out that we are dealing with realistic assumptions.

Annual sales of B are to some extent predictable but monthly shipments are erratic in the highest degree. We learn that this feature has something to do with the unsatisfactory state of plant inventories in the past. In any given month, the link between A and B may, or may not, be important to our inventory plans: whether it is or not depends on shipments of both A and B and the latter are quite unpredictable.

We are confronted with a random variable - in fact, with several of them.

Nor is this the end of the probabilistic element. The plant manager brings out in conference that his production efficiency depends on water supply: and just in the hot months when the Sales Department wants him to get out shipments, he says, the chance of the river drying up is greatest.

The risk of drought is hard to define. Some years the river dries up, some years it doesn't, some years it dries up but shipments are down anyway and it doesn't matter.

At this stage we have identified some and perhaps all the important variables that affect the system we are trying to develop -- that is, the proposed level production and inventory system.

Various ways to proceed with the analysis will occur to you. In any case, with the method we are discussing, the next step is to simulate the behavior of the variables we have identified, including the behavior of Product A and Product B -- thus creating a Monte Carlo routine, with which we can experiment cheaply.

For Product A in particular we want to simulate demand with a seasonal trend which nevertheless behaves in a random manner. Accordingly one of our first requirements will be a reliable source of random numbers; and since we are sticking to hand methods, we will most likely draw these from one of the published tables, such as the Rand Corporation's book, "A Million Random Digits."

At least as a first approximation we will assume monthly demand for Product A is normally distributed around a mean. But evidently the variable is not independent of time. As an experimental tool, then, we settle on these distributions:

> Slide showing three probability distributions of demand for A, each associated with different months of the year. Brief discussion.

The probability of demand for B is distributed in a simpler way since it is independent of time. In fact, the erratic character of monthly demand for B means that the underlying probabilities are equal or nearly so.

> Slide showing probability distribution of demand for B. Brief discussion.

Now just to check our procedure, before going on suppose we run out our simulation for a couple of years and see how the resulting monthly orders for the two products look:

> Two slides showing simulated demand for each product, by months for two successive years. Brief discussion.

Before putting these parts of the simulation together, we must allow for the effect of possible water shortage at the plant.

In deciding how to handle this we need to consider three facts:

> first, that the larger effects, that is the greater droughts, will evidently be less probable;

second, however, the probability of a drought interfering with plant operations will obviously be proportional to the level of production scheduled at the plant;

third, these probabilities are not independent of time since we know droughts are more frequent in summer at this plant location.

If one were seeking a definitive theoretical representation, all this might present quite a nice little problem. But like many of the pieces of wire and tape apparatus that do the job in experimental laboratories, a workable simulation of the drought effect proves quite easy to develop for our purposes.

Slide showing probability distribution of cut in production capacity due to water shortage. Discussion of the way this particular distribution meets the above three conditions.

Now that we have set up our equipment for experiment, we can proceed to use it.

Trying to do this with the help of a desk calculator only, one might proceed as follows.

The basic relationships, or equations, of the system tell us that plant inventory at the end of any month equals inventory starting that month plus needed production of Product A, plus needed production of B, plus production of A or B forced by the other, less shipments: to have these figures in equivalent density units, the raw figures for B are simply multiplied by the ratio of the apparent density of B to that of A.

Accordingly in the first column of our work sheet we might list random numbers, next the corresponding monthly demands for A as determined by the three distributions shown in our slide a moment ago. Then similarly random numbers and the resulting demands for B: next columns for monthly production of both products as determined by some one given production policy; then random numbers and the resulting adjustments for water shortage; and finally end-of-month plant inventory as calculated from the foregoing figures substituted into the basic equations of the system.

Suppose one did this on a sheet of 48 lines, that is, for 48 months of hypothetical operation under any one given production policy - the policy, say, of producing 10,000 tons per month of Product A.

This work sheet could be analyzed to give:

the average monthly plant inventory in equivalent density units

the number of times shipments were delayed due to lack of stock

the number of times plant storage capacity was exceeded implying storage elsewhere in rented space

We would want to repeat the whole experiment with different random numbers until statistically stable results were attained. For example, four repeats or 192 months of simulated operation might prove to be enough.

We would then finally have, as the result of our experiment, just one point on a chart, e.g., a chart with vertical axis average plant inventory and horizontal axis number of tons produced per month.

We would have confidence limits around the point and these, we assume, are sufficiently narrow with the sample of 192.

The next step would be to change the production level from 10,000 to, say, 11,000 tons per month and run 192 cases of this, gaining another point for our chart - and so on until we could say in general how average inventory at the plant depends on monthly production level.

The number of points needed would be determined by several things including plant capacity, sales levels, and the sensitivity of plant inventory to production level. Supposing we needed six points, we would have had to run six of our 192-line work sheets to get the data.

But we have been holding all the other relevant influences or parameters constant. Perhaps we next want to assume a different demand distribution for Product B, this distribution representing one parameter in our system. To completely analyze the results of four different demand distributions for B interacting with 6 different production policies for A would require 24 different experiments, each carried to a statistically stable sample.

Now in a typical industrial problem there might be five different parameters, like the two we have been discussing, and if each of them took on five different values, more than 3000 replications of the experiment would be required to

examine all their interactions. This would hardly be acceptable even with the most rapid computational aids now in existence. However, a good or even fair experimental design could cut this down to a number in the hundreds.

Even so, if each replication of an experiment of, say, 192 lines, required four or five hours with a desk calculator, you can see that more advanced computational equipment must forcibly enter consideration at this point.

We know the big electronic computers, such as the UNIVAC or IBM 700-series, possess the required speed. For instance a recent probability experiment in our group, estimated to require a minimum of 200 man-hours by pencil and paper methods, took nine minutes to run on our computer - which is the Remington-Rand 1103 or so-called "scientific UNIVAC". This ratio of approximately 1300 to 1 is just about what one requires to make possible Monte Carlo experimentation on industrial situations of the kind we have been discussing.

Just consider the parameters and variables we undertook to manipulate in our production-scheduling problem. They were as follows:

Monthly demand for A and B
(we assumed shipments equal demand if stock is available).

Water supply.

Dependence of A on B (we took this to be a constant).

This, with a few additional constants, makes up the list, and would prove sufficient to test our ingenuity if we lacked computational equipment.

For a really productive study of the problem, however, one feels instinctively that more factors ought to be considered; among others are:

Annual mean demand, A & B

Demand, production schedule, shipments separately
(i.e., effect of estimating errors and time lags).

Storage capacity.

Possible grade or quality of raw materials and product.

Then there is a whole group of factors that one would want to take in at the second stage of analysis if not the first, these include:

Costs, prices and profits for both products.

Storage costs.

Cost of money.

Tax rates as affected by the modified system.

Starting off to program the simulation for a fast computer, one would either include all these conditions right off, or make provision for building them in later.

Of course, there is no reason why punched-card equipment cannot be used in this work. I believe a majority of the early Monte Carlo applications in physics were programmed for punched-cards; and I would recommend trials with such equipment wherever computer time is not to be had.

But in practice the electronic computer does seem to be the natural tool for handling the worthwhile problems, especially industrial problems and problems in military logistics.

It will be instructive, I believe, to look now at one such problem which we have handled on the computer all the way through.

This is a military supply problem which, however, is identical in form to certain problems encountered in industry.

Here our research assignment is to determine a system for maintaining optimum depot stocks of the items which go to clothe the American soldier all over the world.

Now, these items are correlated: that is, we must supply not only a jacket but also trousers, gloves along with parkas, socks with shoes, and so on.

In addition most of these items have to be supplied in sizes - some in very many sizes. The standard shirt comes in 30 sizes, the combat boot in 45.

Also from the nature of the military mission, each stock of each size of each item must occur in the proper quantity at each of several geographical locations. By proper quantity we mean enough to minimize the risk of failure to equip the soldier, but not enough to waste money and resources urgently needed for other things.

Note that this problem closely resembles in form the problem of maintenance stocks for a large railroad, although the two are not of course identical.

The situation is complicated by long lead-time, meaning time from cut-off of accounting data to delivery of goods ordered on the basis of this data. This lead-time for the items we are discussing is nine months.

Let us begin where we left off with the other problem, as one would normally do when planning to use a computer, that is by considering the important variables which we will want to subject to experimental control.

The most important of these are:

Demand for an item.

Number of sizes of the item.

Percentage distribution of demand by size and estimate of the same.

Frequency of estimating the percentage distribution.

Lead time.

Maximum and minimum allowable levels of stock.

Number of overseas theaters requiring supply.

Number of storage depots.

Delinquencies or delays in deliveries from manufacturers.

Estimates of future requirements and number of different occasions on which such estimates have to be made (depending on lead time and other features of the system).

Some of these variables, in turn, are aggregated from fundamental variables - this being particularly true of military demand for an item. In order to get more deeply into this I think we had better go over now to the schematization of the system for simulation on the computer. This is one of the steps in treating these complex systems analyses where the collaboration of industrial engineers is so important.

These schematizations constitute an intermediate or transition step: they must be based on accurate and detailed procedural flow diagrams; they lead to a computer flow chart and numerical program code.

Now keep in mind the theory of these experimental models: if successful, our model or schematization will capture all the important features of the system and omit all the unimportant features: this is where judgment, feel for the system, and experience of the experimentalist play their part.

Slide showing period estimate of requirements.
Discussion of the several elements aggregated to give estimated total requirements.

Three slides showing period estimates phased in time and two permutations of the estimating procedure.
Discussion of the technic of determining the possible variations in procedure and testing on the computer.

Slide showing procurement phased in time.
Brief discussion.

Evidently an important feature of our experimental routine will be the method of generating numbers for input to the simulation. Take demand on the system. The characteristics of demand will be determined by field study of actual operations. Then a valid mathematical representation will be decided upon. One that we use in the present problem is this:

Slide showing mathematical simulation of demand which permits relating the state of demand to its previous state.

When we have the complete simulation on the computer, and have survived the debugging phase to get it working, we finally are ready to experiment.

We proceed systematically to answer the key questions required for solution of our problem, such as, in the present case:

How do stocks vary with variations in demand?

Does the number of sizes of an item effect the size of stocks?

For given probability, or risk, of running out of stock, and given distribution of fluctuations in demand estimates, what are the smallest feasible operating stocks of a multi-sized item?

Of course generating these answers in quantitative detail, analyzing, determining the confidence limits, and finally generalizing the results, is a time-consuming process which we are skipping over rather briefly here today.

With the computer, as distinguished from clerical routine, there are certain points of experimental technic which become important.

For instance, working with clerks one would take the raw results of computation for analysis. With the computer, self-analysis routines are a possibility. In the problem I just outlined for you we found that we were analyzing the inventory data from the computer by making frequency distributions and, in some cases, computing up to the fourth moments of the distributions. It finally occurred to us to modify our routine and let the computer produce frequency distributions instead of raw data.

The particular computer we use, the Remington-Rand or ERA 1103 as I mentioned, is exceptionally fast inside but, being designed for scientific use, has a relatively slow output. Accordingly it not only began producing frequency distributions with their first four moments for us, saving nearly an hour of clerical analysis time per experiment, but it did this in 50% less computer time than had been required to produce the raw data.

These questions of technic often involve adaptation to the crotchets of the particular computer with which one happens to be working.

Another point, of great practical importance in the Monte Carlo method, is generation of random numbers; but I will not have time for discussion of this today.

Finally, I'd like to mention a slight bonus which sometimes comes with these methods - in cases where your company is already planning to go over to a big computer for accounting or other purposes.

In the kinds of simulation we've discussed, one programs for the computer a very close approximation to the system he is trying to analyze and improve. If the problem is solved successfully, then, and we pass on to the pilot plant stage, we may find that much of the hard work of translating systems and procedures to the digital computer has already been accomplished in the research stage. This appears as a bonus from the experiment, and may prove quite helpful to the engineer and accountant during installation.

Well, our time is about up.

We've shown that the Monte Carlo method can be applied to systems research in industry: that while in theory the method does not rely on computational equipment, in practice to a great extent it does.

I've tried to picture some of the kinds of industrial situations in which the probabilistic approach is suggestive and promising, and in which my personal experience leads me to believe it will work.

There is just one more point I'd like to make, and that has to do with interdisciplinary cooperation.

These methods permit - and as I see it, require - the joint efforts of accountants, engineers, economists, mathematicians, experts in management and business systems, and statisticians.

Here we have methods sufficiently powerful to permit experimenting with many variables simultaneously: we can study the interaction of competitive elements in sales, the parameters of inventory theory and scheduling, price behavior, and the availability of labor and capital as these all effect a given system. But by the same token, the cooperation of every discipline is needed to control and fully use this power.

In bringing about such cooperation it seems to me the Industrial Engineers can, if they choose to do so, play a key part.

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Dr. Ackoff received his Bachelor of Architecture degree in 1941 and his Ph.D., Philosophy of Science in 1947 from the University of Pennsylvania.

From 1941 to 1942, and again from 1946 to 1947, Dr. Ackoff was an Instructor in the Philosophy of Science at the University of Pennsylvania. During the years from 1942 to 1946 he served with the U. S. Army. From 1947 to 1951 he was Assistant Professor in Mathematics and Philosophy at Wayne University, and from January to August 1950 served as Consultant to the U. S. Bureau of the Census. He was a Research Associate, Project Doan Brook (Operations Research Section), 1951-52.

Dr. Ackoff has served as a consultant for the following: Philadelphia City Planning Commission, 1946-47; Task Force on Ultimate Consumer Goods, ASTM, 1947; and Naval Ordnance Test Station, 1951. He was Managing Editor, Bulletin of Inst. of Experimental Method 1946-47, on the Abstracting Staff, Biological Abstracts, 1950-51, Book Review Editor, Philosophy of Science, 1948-1953, and is Associate Editor, Journal of the Operations Research Society of America.

Dr. Ackoff is the author of the following publications: Psychologistics (monograph) with C. W. Churchman, University of Pennsylvania Faculty Research Fund, 1946; Measurement of Consumer Interest, edited with C. W. Churchman and M. Wax, University of Pennsylvania Press, 1947; Methods of Inquiry, with C. W. Churchman, Educational Publishers, 1950; The Design of Social Research, University of Chicago Press, 1953; and has had articles published in: Journal Operations Research Association of America; Management Science; Industrial Laboratories; Social Forces; Philosophy of Science; International Journal of Opinion and Attitude Research; Advanced Management.

He is a charter member, Fellow, and was Vice President (1954) of the Operations Research Society of America, and is also a member of the Institute of Management Science, the American Statistical Association, and the American Philosophy Association.

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Dr. Aiken received his B. S. degree in 1923 from the University of Wisconsin, attended the University of Chicago 1931-1932, and received his M. S. in 1937 and his Ph. D. in 1939 from Harvard University. He also has received an honorary doctorate in engineering (1952) from Technische Hochschule Darmstadt and an LLD (honorary) from Wayne University (1954).

From 1923 to 1927, Dr. Aiken was an operating engineer while an undergraduate with Madison Gas and Electric Company. At Harvard University, from 1939 to 1941 he was a faculty instructor in physics, from 1941 - 1946 he was Associate Professor of Applied Mathematics, and from 1946 he has been Professor of Applied Mathematics. During World War II he served as a Commander in the USNR from 1941 - 1946.

Dr. Aiken is the recipient of many decorations and honors, including the following: Palmes de l'Academie Francais (1949); Chevalier, Legion of Honor (1952); Ingeniors Vetenskaps Akademien (1950); National Fonds voor wetenschap Pelijk Onderzoek (Belgium) (1951); Consejero de Honor del Consejo Superior de Investigaciones Cientificas (Spain) (1952); Ralph E. Hackett Award (Science) (1954); Officer's Cross of the Order of the Crown (Belgium) (1955); Navy Distinguished Public Service Award (1955).

An active member of many professional societies, his memberships include the following: Fellow, American Academy of Arts and Sciences; Fellow, Association for the Advancement of Science; Econometric Society; Honorary member of Phi Beta Kappa; Sigma Xi; Gesellschaft fur Angewandte Mathematik und Mechanik; Kungliga Vetenskaps - och Vitterhets-Samhallet (Goteborg).

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Mr. Alberts is a mechanical engineering graduate of the University of Wisconsin and served as Director of Operations for the Second Air Division during World War II. He joined United Air Lines in 1946 and has held such positions as Special Assistant to the Vice President, Operations, and Assistant to the Vice President of Flight Operations. He is presently Director of a Management Engineering Group which serves as an internal consultant to the rest of the company.

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Dr. Alexander received both his A. B. degree in Physics and the B. S. degree in Electrical Engineering in 1931 from the University of Oklahoma and was awarded a Tau Beta Pi Fellowship for graduate studies. In 1933 he received the M. S. Degree in Electrical Engineering from the Massachusetts Institute of Technology, where he continued his graduate studies under a Coffin Foundation Research Fellowship for 1934.

From 1935 to 1940 Dr. Alexander was a Laboratory Engineer, Simplex Wire and Cable Company. From 1940 to 1943 he was a Physicist with the Navy Department on electronic instrumentation. During the period 1943 to 1946 he served as Senior Project Engineer with Bendix Aviation Corporation on development of telemetering equipment. From 1946 to 1954 Dr. Alexander was with the Electronic Computers Laboratory, National Bureau of Standards, on development of digital computer technology and was overall supervisor of design and construction of SEAC and DYSEAC. Since 1954 he has been with the Data Processing Systems Division, National Bureau of Standards. This activity grew out of the earlier computer development program and now includes application of both digital and analog systems for data processing and dynamic control.

Dr. Alexander has been active in a variety of special activities, including: Member of Advisory Committee on Electronic Computers for Defense Business Applications; Member of Task Force on Paperwork Management, Hoover Commission; and member of the Advisory Committee on Application of Machines to Patent Office Operations. He is also special technical consultant to several agencies of the Government on automatic processing of routine paperwork.

Dr. Alexander is an honorary member of Phi Beta Kappa, Sigma Tau, Sigma Xi, and Tau Beta Pi. He holds the following professional memberships: Fellow of The Institute of Radio Engineers; Member of American Institute of Electrical Engineers; The Association for Computing Machinery; The Institute of Radio Engineers and their Professional Group on Electronic Computers and on Instrumentation. Has served on a number of technical and standards committees of these societies.

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Mr. Allen attended the University of Wisconsin, and after completing Cudahy's Student Training Program became Senior Time Study Engineer for the Cudahy Brothers Company.

As Chief Industrial Engineer for the Cudahy Brothers Company, Mr. Allen supervises production standards, methods and statistical quality control. Prior to his current assignment, Mr. Allen was supervisor of the Company's Cost Department.

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Dr. Ralph M. Barnes is an engineering graduate of West Virginia University. He received his M.S. and Ph.D. degrees from Cornell University.

He has been associated in engineering capacities with such organizations as: Bausch and Lomb Optical Company, The Gleason Gear Works, Eastman Kodak Company of Rochester, New York, and the LaCrosse Rubber Mills Company. He has served as consulting engineer for industrial organizations in this country and abroad.

During the summer of 1950 he served as Consultant for the Industrifor Bundets Rationaliseringskontor A/S (Federation of Norwegian Industries), and the Federation of Swedish Industries. He directed a three-week Management Course in Oslo and a shorter course in Stockholm for these organizations.

During the Spring of 1956 he served as consultant to the Government of Spain in developing plans for the establishment of a School of Industrial Administration in Madrid.

Professor Barnes is the author of several books on engineering and production management, including: "Motion and Time Study", 3rd Ed. (translated into Spanish, Italian and French), "Work Measurement Manual," 4th Ed., "Industrial Engineering and Management," and "Work Methods Manual."

He is a Vice President of the Society for Advancement of Management and is a fellow of the American Institute of Industrial Engineers, The American Society of Mechanical Engineers, and The American Association for the Advancement of Science.

DR. GLEN DARWIN CAMP

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Dr. Camp received his B.S. degree in Chemistry (minor physics) in 1927, his M.A. degree in Physics (minor mathematics) in 1933, his Ph.D. in Physics (minor mathematics) in 1935, all from the University of California. In addition he engaged in post-doctoral work in physics at Stanford University in 1937.

Prior to 1942, Dr. Camp was Professor of physics, City College of San Francisco; graduate student, Univ. of Calif; instructor of physics and mathematics, Deep Springs College; research associate, Mass. Inst. of Tech.; research chemist, Union Oil Company (Edeleanu process); junior research chemist, Atmospheric Nitrogen Corporation (routine research on synthesis and oxidation of ammonia); undergraduate student, Univ. of Calif.; oil well driller's helper, Pacific Oil Company; timekeeper and junior engineer, excavation contractor; office boy, clerk and service station salesman, Standard Oil Company of California.

From 1942 to 1946 he was, in turn, an Associate Physicist, physicist, and head, Crystal Transducer Laboratory, University of California, Division of War Research where he engaged in the following activities: Underwater sound transmission; design and construction of crystal transducers; sea-trials of sonar gear; development of sound-head of FM Scanning Sonar which contributed to the safe passage of nine US submarines through mine fields in Straits of Tsushima; acting editor and senior author, OSRD Summary Tech. Vol. 12, "The Design and Construction of Crystal Transducers for Underwater Sound Applications".

From 1946 to 1951 Dr. Camp was with the Massachusetts Institute of Technology, Division of Industrial Cooperation, as Senior Staff Member, Operations Evaluation Group, assigned to Office of the Chief of Naval Operations; OEG submarine desk; scientific adviser to Admiral C. B. Momsen, Asst. CNO for Undersea Warfare. His activities there included observational, experimental and theoretical studies of naval combat and logistics operations; pro- and anti-submarine warfare; mining and mine countermeasures; convoy and harbor operations; operational evaluation of nuclear-powered submarine.

DR. GLEN DARWIN CAMP
(Continued)

At Melpar, Inc., from 1951 to the present time, Dr. Camp has been responsible for the formation and direction of OR group to study railroad operations for goodwill of major customers and to guide new-product development; consultation on technical and operational problems.

His military service and exerpience not only included application of Operations Research to naval operations; OEG 1946-51, as indicated above, but also the following: Graduate, Submarine Command Course, U.S. Navy Submarine School, New London, 1946. 2nd Lt., 1st Lt. US Army Reserves, 1927-33; honorable discharge, 1933. ROTC, Univ. of Calif., 1923-27.

Dr. Camp is the author of many publications, including the following unclassified and de-classified works: Cost of Delivery Via Distribution Networks, to appear shortly; Inequality-Constrained Stationary-Value Problems, JORSA 3, No. 4, 1955; Operations Research: The Science of Generalized Strategies and Tactics, Textile Res. Jour. XXV, 629, 1955; Bounding the Solutions of Practical Queueing Problems by Analytic Methods, Johns Hopkins Univ. Press, 1954; Feedback Control of Continuing Operations, JORSA 1, No. 3, 1953; A Variational Method for Linear Dissipative Anisotropic Elastic Systems, Phys. Rev. 69, 502, 1946; Impedance Representation of Tangential Boundary Conditions, Phys. Rev. 69, 501, 1946; The Design and Construction of Crystal Transducers for Underwater Sound Applications, OSRD Summary Tech. Vol. 12; with five co-authors; Heavy-particle Interactions from Beta-decay Theory, Phys. Rev. 51, 1046, 1937; Relativistic Non-conservative Theories of Gravitation, Docotral Thesis, Univ. of Calif. Press, 1935.

He was an Amy Bowles Johnson Memorial Fellow in Physics, Univ. of Calif., 1934; Le Conte Memorial Fellow in Physics, Univ. of Calif., 1933.

He was Phi Beta Kappa, Phi Lambda Upsilon, Pi Mu Epsilon, Scabbard and Blade, Sigma Xi, Tau Beta Pi.

Dr. Camp is a member of the American Marketing Association; American Physical Society (Fellow); Cosmos Club, Washington, D. C.; Econometric Society; Institute of Management Sciences; Institute of Radio Engineers; Operations Research Society (Fellow; Council Member, 1954-57; Chairman, Washington Section, 1955); and Washington Philosophical Society.

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Dr. Christie received his Ph.D. in Psychology from the University of California in 1951. He was a member of the staff of that University as Lecturer in Psychology during the period 1950-1951.

During the period 1951-1953, Dr. Christie was a member of the staff, Research Laboratory of Electronics, and Instructor, Department of Economics and Social Science, Massachusetts Institute of Technology. He was Principal Investigator and Assistant Professor of Psychology, Department of Systems Analysis, Tufts University during 1953-1954. In 1954 he joined the staff of the Operations Research Office, The Johns Hopkins University where he now holds the position of Group Chairman.

He was an officer, USNR, 1944-1946.

DR. JOHN J. CORSON

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Manager, Washington, D. C. Office

Dr. Corson received his B.S. degree in 1926, his M.S. in 1929, and his Ph.D. in 1932 from the University of Virginia.

From 1933 to 1935 he was Head of the School of Business Administration, University of Richmond, Virginia. From 1949 to 1953 he has been a lecturer at Columbia, Cornell, Princeton, and George Washington Universities. More recently he has been conducting courses in Executive Development at Cornell University.

His business experience includes the following: from 1936 to 1937, Dr. Corson was Assistant Executive Director, Social Security Board; from 1943 to 1944 he was Director, Bureau of Old Age and Survivors Insurance, Federal Social Security Administration; from 1941 to 1942 he was Director, U. S. Employment Service; in 1943 he was a member of the Advisory Board to the Provost Marshal General, U. S. Army, and also Consultant to the Mexican Institute for Social Security; in 1944-45 he was Deputy Director General, UNNRA; from 1945 to 1951 he was Executive, the Washington Post; and from 1951 to 1953 he was Manager, Washington office of McKinsey and Company, a post he still holds in addition to having become a partner in the firm.

DR. JOHN J. CORSON
(Continued)

Dr. Corson is the author of "This Government" (1938), "Manpower for Victory" (1943), "Executives for the Federal Service" (1952), "Economic Needs of Older People" (1956) in collaboration with J. McConnell, and articles in Atlantic Monthly, the Nation, New York Times Magazine, The Survey, and other publications.

Dr. Corson was President, American Society for Public Administration, 1948-1949; and is a member of American Economic Association, American Welfare Association, and American Political Science Association. He was a member of the Advisory Council on Personnel to Lt. General W. S. Paul, G-1, Department of the Army, 1946-1949; a member of the Advisory Council to the Comptroller of the Army, 1949-1951; Public Member of the Advisory Council to the U. S. Employment Service, 1945 to date; and Executive Vice Chairman, College Grants Advisory Committee, Ford Foundation.

DR. ROGER R. CRANE

Manager of Research, Management Sciences
Touche, Niven, Bailey and Smart
Certified Public Accountants
Detroit, Michigan

Dr. Crane received his B.A. from the University of Toronto and his S.M. from the Massachusetts Institute of Technology. He has engaged in additional studies at Harvard, University of Maryland and Catholic University of America.

Dr. Crane joined the executive offices of the national accounting frim of Touche, Niven, Bailey and Smart in December 1955, to direct nationally the activities of this firm in the management sciences. Before joining the staff of this firm, he served as Director of Operations Research, Melpar, Inc., a subsidiary of Westinghouse Air Brake Co. and subsequently in the same capacity for the parent company in Pittsburgh.

Prior to joining Melpar, Inc., Dr. Crane was a senior member of the research staff, Massachusetts Institute of Technology, serving in the Navy's Operations Evaluation Group. He has also been a member of the scientific staff, Naval Research Laboratory, Washington, D. C., and the California Institute of Technology.

He is a member of the Operations Research Society of America, the Institute of Management Sciences, the American Railway Engineering Association and Sigma Xi.

SAMUEL W. EARLE

Industrial Engineering Section - Management Services Department
Union Carbide and Carbon Corporation
New York, N. Y.

Mr. Earle received his degree of Bachelor of Science in Civil Engineering in 1946, and the degree of Master of Science in Industrial Engineering in 1948, both from Purdue University.

In 1946 Mr. Earle joined the Haynes Stellite Company, a division of Union Carbide and Carbon Corporation. After holding various positions involving work in cost analysis, materials handling and methods improvement, office layout, and general industrial engineering, in 1951 he was appointed head of the Methods Standards and Plant Layout Department. He transferred to his present position in 1953. Recently, he has also begun the formulation of divisional Industrial Engineering Groups through training and consultation.

Mr. Earle has been a guest lecturer at the Top Management Seminar of the Army Ordnance Management Engineering Program at Rock Island, Illinois, guest lecturer at Marquette University, and was a speaker at the first annual Work Measurement Clinic (1955), jointly sponsored by the AIIE and University of Austin, at which time his talk was entitled "Work Measurement in a Process Industry". He has also participated in various materials handling conferences as chairman or panel member.

Mr. Earle is the co-author of an article on materials handling entitled "Cycle Conception", a feature of which is a set of study symbols called "handligs". Also, he has supplied data for the Memomotion Section of the "Handbook of Industrial Engineering", a forthcoming McGraw-Hill publication. He has conducted courses in elementary mathematics at the Kokomo Extension of Indiana University and statistical quality control for Adult Education - Foreman's Club, Kokomo, Indiana.

GORDON R. EWING

Internal Management Consultant and Manager of Industrial Engineering,
Crawfordsville, Indiana, plant, R. R. Donnelley & Sons Company
Chicago, Illinois

Mr. Ewing graduated from the California Institute of Technology in 1935 with the degree of Bachelor of Science, and received his Master of Business Administration degree in 1937 from the Harvard Business School.

GORDON R. EWING
(Continued)

From 1937 to 1941, Mr. Ewing was employed as an engineer-analyst by The Chicago Corporation, an investment trust. During World War II he developed expediting methods and performed manufacturing analyses for the Chicago Ordnance District. From 1945 to 1948, Mr. Ewing directed the manufacturing activities of the Clark Division of the McCraw Electric Company. In 1948, he participated in a management survey of the U. S. Maritime Commission as a member of the professional staff of the Expenditures Committee of the United States Senate. Mr. Ewing has been with R. R. Donnelley & Sons Company for the last six years as an internal management consultant and as Manager of Industrial Engineering for the company's Crawfordsville, Indiana, plant.

In addition to being a Director of the Central Indiana Chapter of the A. I. I. E., Mr. Ewing is a member of the Econometric Society, The Operations Research Society of America and The Institute of Management Sciences.

DR. ROBERT B. FETTER

Assistant Professor of Industrial Management
Massachusetts Institute of Technology
Cambridge, Mass.

Dr. Fetter received his B.S. degree in Electrical Engineering from Virginia Polytechnic Institute in 1947, and his M.B.A. (1949) and D.B.A. (1952) from Indiana University.

From 1949 to 1952, Dr. Fetter was Instructor in Management, and from 1952 to 1953, Assistant Professor of Management, at Indiana University.

Dr. Fetter has conducted research in "Application of Waiting Line Theory to Problems of Maintenance Management" and on "Analog Computations of Some Business Decisions".

He is a member of the American Economic Association and the American Statistical Association.

FREDERICK M. GILBRETH

McKinsey & Company
Management Consultants
New York, N. Y.

Mr. Gilbreth received his B.S. degree in Mechanical Engineering from Brown University.

Before joining McKinsey & Company in 1945, Mr. Gilbreth served in the U. S. Army Air Corps in Europe during World War II. Previously, he was an industrial engineer with Merck & Company, and prior to that, with R. H. Macy & Company.

With McKinsey & Company, Mr. Gilbreth is chiefly concerned with studies of client problems in manufacturing, engineering, and organization. He has assisted companies in a wide range of industries to improve their operations in these areas.

Mr. Gilbreth is a member of the American Society of Mechanical Engineers and has participated actively in the Management Division. He has spoken on a variety of subjects dealing with the operation of large business enterprises and has studied the relative effectiveness of certain staff departments in various types of businesses.

He is probably also known to many as a member of the Gilbreth family, whose story was related in "Cheaper by the Dozen" and "Belles on Their Toes".

DR. WILLIAM GOMBERG

Director, Management Engineering Department
International Ladies' Garment Workers' Union, AFL-CIO
New York, N. Y.

Dr. Gomberg received his B.S. degree from the City College of New York, his M.A. degree from New York University, and his Ph.D. from Columbia University.

Prior to becoming Director of the Management Engineering Department, Dr. Gomberg worked for the ILGWU as an organizer and as a business agent for one of the large New York locals of the Union. Under his direction, the Management Engineering Department of the ILGWU, AFL-CIO, furnishes a free consulting engineering service to garment manufacturers in contractual relations with the Union. A staff of trained engineers and technicians assist the managements of garment plants to make better and fuller use of their plant productive facilities, thereby enabling the workers to increase their output and improve their earnings proportionately. The Department is also charged with the policing of piece rate policies developed by divisions of the Union.

DR. WILLIAM GOMBERG
(Continued)

Because of its pioneering work in the field of industrial engineering, the Department has been called upon for consulting work by t h e United Automobile Workers, AFL-CIO; International Association of Machinists, AFL-CIO; United Textile Workers, AFL-CIO; Commercial Telegraphers Union, AFL-CIO; United Rubber Workers, AFL-CIO; and others.

Dr. Gomberg has served as consultant to the Economic Cooperation Administration and the Mutual Security Administration. In this capacity he has completed three missions to Europe (1950-1952). He has also served as the union member of the tripartite arbitration panel set up following the strike over a production standards dispute between the Ford Motor Co. and the UAW-CIO, June 1948.

Dr. Gomberg is the author of a TRADE UNION ANALYSIS OF TIME STUDY, 2nd edition, Prentice-Hall, Inc., 1955, and A LABOR UNION MANUAL ON JOB EVALUATION, Labor Education Division, Roosevelt College, Chicago.

In addition to the American Institute of Industrial Engineers, Dr. Gomberg is a member of the following organizations: American Arbitration Association, American Economic Association, American Society for Mechanical Engineers, American Statistical Association, Institute of Mathematical Statistics, Professional Engineers' Society, Society for Advancement of Management, and the National Association of Cost Accountants.

In addition to lecturing before these and many other professional engineering organizations and before numerous college classes throughout the country, he has written articles for such journals and publications as: Industrial Engineer, Mechanical Engineering, The Bent of Tau Beta Pi, Modern Management, Harvard Business Review, the Bureau of National Affairs Service, the Annals of the American Academy of Political and Social Sciences, Industrial and Labor Relations Review of Cornell and Personnel.

He is currently Adjunct Professor of Industrial Engineering at Columbia University.

Dr. Gomberg will speak on "THE DEVELOPING RELATIONSHIP BETWEEN COLLECTIVE BARGAINING AND INDUSTRIAL ENGINEERING SINCE THE CLOSE OF WORLD WAR II"

(Session 1A, Industrial Engineer's Labor-Management Role, 17 May 1956, AIIE 7th Annual National Conference)

JOHN P. JUNG

Methods Engineer
Industrial Engineering Department of the Television & Radio Division
Philco Corporation, Philadelphia, Pennsylvania

Mr. Jung received his B.A. from the Commonwealth of Pennsylvania in 1931 with supplementary studies in Business and Management at Banks, Temple University and Penn State College. Prior to joining Philco Corporation, Mr. Jung graduated from Radio Electronic Institute, Inc., in Philadelphia, Pennsylvania, in electronics engineering. He has also received supplementary management training at the National Institute of Management in Cleveland, Ohio.

Mr. Jung joined Philco Corporation in 1948 as a Time Study Engineer and advanced to the position of Electrical Methods Engineer. In March, 1955, he was appointed Director of Training for the Industrial Engineering Department of the Television and Radio Division. He is presently engaged with the Cost Engineering Department of the Television and Radio Division on cost reduction studies in management-engineering techniques.

He holds memberships in the Institute of Radio Engineers and the Institute of Management Sciences.

DR. HAROLD W. KUHN

Associate Professor of Mathematics
Bryn Mawr College
Bryn Mawr, Pennsylvania

Dr. Kuhn received his Ph.D. from Princeton University in 1949. He was a Fulbright Fellow in France (1950).

In 1951, Dr. Kuhn was a lecturer in Mathematics at Princeton. At present, in addition to being Associate Professor of Mathematics at Bryn Mawr College he is also Consultant to the Office of Naval Research Logistics Project, Department of Mathematics, Princeton University.

Dr. Kuhn's publications in linear programming and the theory of games date from 1948 and include the fundamental duality theorem of linear programming (jointly with David Gale and A. W. Tucker) and, most recently, a new computational method for assignment and transportation problems.

He was President of the Society for Industrial and Applied Mathematics for the year 1954-55.

DR. IRWIN P. LAZARUS

Acting Director, Ordnance Management Engineering Training Program
Rock Island Arsenal
Rock Island, Illinois

Dr. Lazarus received his B.S. in Aeronautical Engineering; M.S. in Industrial Engineering; and Ph.D. in Industrial Engineering from Purdue University.

He has served as Industrial Engineer, Atlas Brewing Company; Research Engineer on US Army Ordnance Project #PRF 679; Partner in the firm of M. E. Mundel and Associates, Consultant Industrial Engineers; and Conference Leader, Ordnance Management Engineering Training Program. He was Assistant Professor of Industrial Engineering at Purdue University and served as lecturer at Michigan State University, Marquette University, University of Minnesota, and State University of Iowa. He has taught Motion and Time Study, Industrial Organization and Management, Advanced Seminar in Motion and Time Study, as well as Theoretical and Applied Mechanics and Strength of Materials. He also has served in the U. S. Navy as Aircraft Engineering Officer.

He is the author of "The Nature of the Stop Watch Time Study Error", Advanced Management, May, 1950; "Predetermined Time Standards in the Army Ordnance Corps", Journal of Industrial Engineering, November 1954; Chapter 25 of Motion & Time Study Principles and Practice, Edition 2 by M. E. Mundel, Prentice-Hall, New York, 1955.

He is a member of the Society for the Advancement of Management; American Society for Engineering Education; American Institute of Industrial Engineers - Vice President, Midwest Region for 1957; Rotary International, Recipient of Government Superior Accomplishment Award, November, 1954.

He is presently employed as Acting Director, Ordnance Management Engineering Training Program, Rock Island Arsenal, Rock Island, Illinois, in which capacity he supervises and coordinates staff of the central management consultant and training group serving 97 U. S. Army Ordnance Corps installations and their 130,000 civilian employees. He is listed in American Men of Science, 9th Edition.

LIEUTENANT L. L. KORNFELD, SUPPLY CORPS, U. S. NAVY

Management Engineering Division, Bureau of Supplies and Acco
Department of the Navy,
Washington, D. C.

LT Leo Kornfeld, SC, USN, was educated at the University of Michigan and Georgia Tech. He has acquired three degrees: B.S. in Mathematics, a Bachelors and Masters in Engineering. He is working towards his doctorate degree in Industrial Engineering at New York University. He is a member of Tau Beta Pi, the Engineering honor society.

He is a career Navy Supply Corps Officer and has had varied duties both afloat and ashore. He has held such positions as the supply officer of a Naval vessel, assistant Planning Officer of a Navy Storage and Distribution point, and Factory Officer at the Naval Clothing Factory where he was primarily responsible for developing the time standards program for 2000 production workers. At present, he is assigned as the Special Assistant to the Management Engineering Division officer of the Navy Department's Bureau of Supplies and Accounts in Washington, D. C. In this position, he is primarily involved in the present Bureau of Supplies and Accounts Engineered Time Standards Program which is directing the setting of work standards in the clerical, warehousing, electric accounting machine and public works maintenance areas utilizing Industrial Engineering techniques such as Methods-Time Measurement, Time Study, Yale and Towne Predetermined Standard and Ratio Delay.

DR. ELBERT P. LITTLE

Staff Consultant
Anderson-Nichols & Company
Management Consultants
Boston, Massachusetts

Dr. Little is a graduate of Harvard University, Class of 1934 and received his physics doctorate in 1941 from the same university.

Dr. Little has been on the staff of Harvard, Radcliffe, and Phillips Exeter Academy as well as Wayne University. He has also been technical manager of the Marine Biological Laboratories, Woods Hole, Massachusetts.

Dr. Little is one of the pioneers in the field of integrated data processing. Dr. Little was formerly Chief, Computation Branch, U. S. Air Force, and then Professor at Wayne University, Detroit, where he headed the research and practical studies in the business applications of computers. He is well-known in the field of computers for his teaching and consulting and for his analysis of business systems and industrial procedures.

MR. DONALD G. MALCOLM

Director of Operations Research
Booz, Allen and Hamilton
Chicago, Illinois

Mr. Malcolm received his B.S.P.S.E. and M.S. in Industrial Engineering from Purdue University.

He is now Director of Operations Research, Booz, Allen and Hamilton, Chicago, Illinois. Previously he was Research Leader and Senior Staff Member, Operations Research Office, The Johns Hopkins University. He also has served as Vice-President-Engineering and Production, Bacon Vulcanizer Mfg. Company; as Assistant Professor Mechanical Engineering (Industrial Engineering), University of California; as Instructor to Assistant Professor Engr. Mechanics, Purdue University; and with the Allison Division, General Motors Corp. as production foreman, methods and procedures specialist and calibration engineer.

He is the past national President of AIIE, He also has served in many other officer positions such as President and Director of the San Francisco - Oakland Chapter; National Vice-President, Western Region; Chairman, National Committee on Registration; Board of Trustees.

He is a member of SAM, ASME, American Society for Engr. Education, the Institute of Management Sciences, Tau Beta Pi and Sigma Xi. He is a Registered Engineer and Fellow-American Association for the Advancement of Science.

DR. H. B. MAYNARD

President, Methods Engineering Council
Pittsburgh, Pennsylvania

Dr. H. B. Maynard, a professional management man, is one of the best known figures in the field of management today. Methods Engineering Council, a firm of management consultants, of which he is President and founder, is recognized internationally for its consulting work in virtually every phase of business and industrial enterprise.

Dr. Maynard is one of the originators of methods-time-measuremen (MTM), a technique used to set work and production standards based upon predetermined time units for manual motions. He also is responsible for the now universally accepted phrase, "methods engineering," from which his firm gets its name. In addition, Dr. Maynard has created many other business and industrial techniques in organization, administration, sales and sales management, finance, controls, and training -- as well as his recently announced procedure Universal Maintenance Standards.

DR. H. B. MARNARD
(Continued)

Among the many honors he has received in the management field are the Gilbreth Medal, the Melville Medal, and selection as ASME Towne Lecturer. He is the author and co-author of four technical books now used in colleges and universities. He is much in demand as a speaker before important engineering and industrial groups internationally. Currently he is Editor-in-Chief of the INDUSTRIAL ENGINEERING HANDBOOK to be published by McGraw-Hill. In April of the current year, he was awarded the Wallace Clark Award for his contributions to management on the international scale.

Dr. Maynard has been national president of such professional groups as the Council for International Progress in Management, Inc., the Society for Advancement of Management, and the MTM Association for Standards and Research. He has been a director of the Association of Consulting Management Engineers, and is past chairman of the Management Division, American Society of Mechanical Engineers. He is past president of CIOS, the International Committee on Scientific Management with headquarters in Geneva, Switzerland. Dr. Maynard was in Sao Paulo, Brazil, in February 1954, to preside at the Tenth International Management Congress sponsored by CIOS.

JOSEPH J. MOQUIN

Chief Industrial Engineer
Army Ballistic Missile Agency
Huntsville, Alabama

Mr. Moquin received his B.S. degree in Industrial Engineering from Washington University, St. Louis, Missouri, where he also continued graduate study.

He was Director of the Army Ordnance Management Engineering Training Program from 1953 to 1956. He has also been Industrial Engineer, United Wood Heel Co.; Industrial Engineer, Beltx Corporation; Industrial Engineer, Rice Stix, Inc.; Conference Leader, Ordnance Management Engineering Training Program, and has taught at Washington University, St. Louis, Missouri; been lecturer at University of Wisconsin, University of Minnesota, Purdue University, Marquette University, Michigan State University, St. Ambrose College and University of Illinois He served in the Amry Corps of Engineers. Previous to joining the Army O.M.E.T.P. he was Industrial Engineer at Rice Stix, Inc., St. Louis, Missouri; and Instructor in Industrial Engineering, Washington University.

He is a member of the American Institute of Industrial Engineers

JOSEPH J. MOQUIN

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Mr. Moquin received his B.S. degree in Industrial Engineering from Washington University, St. Louis, Missouri, where he also continued graduate study.

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JOHN F. MUTH

Instructor of Economics
Carnegie Institute of Technology
Pittsburgh, Pennsylvania

Mr. Muth has been associated for four years with a research project in production planning and control at Carnegie Tech and is now an economics instructor at that institution.

His professional interests lie in the field of management science and operations research, as well as in economic theory and econometrics.

JOHN A. NEVROS

Chief, Management Assistance Branch, Management Division
Office of The Quartermaster General of the Army,
Washington, D. C.

Mr. Nevros received his LL.B. degree from Columbus University, School of Law, Washington, D. C., now a part of the Catholic University of America, in 1940. He completed Advanced Technical Training in Business Administration at the Graduate School of Business Administration, Harvard University, in July 1943, and completed courses in Motion and Time Study at the University of Virginia at Richmond, and in Materials Handling at the University of Richmond. He is also a graduate of the Quartermaster School (1942) at which time he was commissioned a 2nd Lieutenant in the Army of the United States, of the Army Service Forces Depot School at Camp Lee and Utah ASF Depot in 1945, and the Army Command Management School (July 1955) at Fort Belvoir, Virginia.

From 1935 to 1946 he held various positions with the National Labor Relations Board, attaining the position of Associate Attorney in 1945. In 1946 he transferred to the New Cumberland General Depot, U. S. Army, at New Cumberland, Pennsylvania, where he served as Director of the Control Division (subsequently redesignated the Management Engineering Division). From December 1946 to the present time he has been with the Office of The Quartermaster General of the Army and has held his present position for the past six years. As Chief of the Management Assistance Branch, Mr. Nevros provides staff direction and technical supervision over the Quartermaster management engineering, industrial engineering and management improvement programs for the QM Field Establishment, approximately 20 field installations with nearly 30,000 personnel.

He served with the Army of the United States from 3 March 1941 to 16 October 1945, first as an enlisted man with the 260th Coast Artillery (Anti-Aircraft), then with the 722nd Military Police Battalion (ZI), and finally as an officer with the Quartermaster Corps at Camp Lee, Richmond ASF Depot, Utah ASF Depot, and in Hawaii. He was assigned principally to management engineering duties from 1943 to 1946.

Mr. Nevros is a member of the Bar of the District of Columbia, being admitted to practice before the U. S. District Court in 1940 and the U. S. Court of Appeals in 1941.

He is a Director of the D. C. Chapter, AIIE, Chairman of the Program Committee and the Proceedings Committee for the AIIE 7th Annual National Conference; a charter member of the Armed Forces Management Association; member of the American Society

JOHN A. NEVROS
(Continued)

for Public Administration and Barristers Lodge No. 48, FAAMasons. He has spoken on management and industrial engineering at the Industrial Club of Schenectady, N. Y., the Washington Chapter of the AIIE, the Management Engineering Institute, at QM installations, and elsewhere. He received the Department of the Army Commendation for Meritorious Civilian Service and Outstanding Performance of Duty in 1952. He was editor-in-chief of the Columbus University yearbook in 1940 and the university newspaper in 1942, both of which received high national intercollegiate ratings.

HARRY L. PALMER

Manager - Engineering, Specialty Control Department
General Electric Company
Waynesboro, Virginia

Mr. Palmer received his BSEE degree from the Washington State College in 1925.

He has been associated with the General Electric Company ever since his college graduation. His experience with General Electric Company includes 5 years in the Radio Engineering Department where he worked on industrial applications of electronic tubes (1925-1930); 8 years in the Industrial Control Department where he worked on industrial electronic applications (1930-1938). In 1938 he was placed in charge of the Industrial Electronic Section of the Industrial Control Department. In January 1953 he was made Sub-section manager of Electronic, Regulator and Aircraft Engineering. In September of the same year he was appointed Manager-Engineering, Specialty Control Department, his present position.

RALPH PRESGRAVE

Vice President, York Knitting Mills, Limited, and
Vice President, J. D. Woods and Gordon, Ltd.
Management Consultants
Toronto, Canada

Born in London, England, Mr. Presgrave attended high school and university in Toronto, Canada. He received his degree of Bachelor of Applied Science (Chemistry) from the University of Toronto in 1921.

Mr. Presgrave has been associated with the Textile Industry since graduation. During the last 27 years he has been with York Knitting Mills, Ltd., in time study, personnel and general supervision. He has been closely connected with Time Study since 1927 and was one of the founders of the firm of J. D. Woods & Gordon Limited, Toronto, Industrial Consultants. Currently he is in charge of personnel and has other management responsibilities in the six mills of York Knitting Mills, Limited, Toronto. He is also Vice President of Kroy Unshrinkable Wolls, Limited, Toronto, Vice President of Thomson Research Associates, Ltd., Toronto, and Director, Kroy, Inc., Lowell, Massachusetts.

Mr. Presgrave is a fellow of the American Institute of Industrial Engineers and was recipient of the Gilbreth Medal in 1951.

He is lecturer on Time Study and related subjects at the Universit of Toronto, Engineering and Institute of Business Administration.

Mr. Presgrave is author of "The Dynamics of Time Study" and numerous papers on Time Study, Labor Relations, and allied subject

He is on the following standing committees: Professionalization Industrial Engineering (S.A.M. (U.S.)); Industrial Engineering Projects (S.A.M. (U.S.)); Chairman, Industrial Relations Committee Woolen & Knit Goods Association, Canada; Industrial Relations Committee, C.M.A.; and Committee on Management Terminology (Canadian repres.) Comite International de l'organization Scientifique.

A gentleman of diverse interests his hobbies include the collection and study of old prints, and color photography. He is a charter member of the Colour Photographic Association of Canada and an exhibitor in International Salons specializing in natural history.

NYLES V. REINFELD

Managing Director, National Institute of Management, Inc.
Cleveland, Ohio

Mr. Reinfeld received his B.A. in Industrial Management from the University of Akron, and his M.A. in Mathematics from the University of Michigan.

Currently, he is Managing Director of National Institute of Management, Inc., formerly known as Executive Services, a consulting and training firm which specializes in industrial training in applied mathematical management. Mr. Reinfeld has worked in the Systems Department, University of Michigan, set up and solved problems SEAC, Mark III, at the National Bureau of Standards, Washington, D. C. He also was with Burroughs Corporation, doing field and systems work for design of office equipment, setting up problems for digital computer (Testrack). He is a former member of the Methods Engineering Council. His primary activities are mathematical programming and inventory management. He worked on the first installation of mathematical programming to industry at SKF. He also worked four years in machine shops in Akron, Ohio. He served in the U. S. Navy.

Mr. Reinfeld's publications include articles in Tooling and Production, Iron Age, Steel Magazine, Business Week, Journal of Operations Research, and Journal of Institute of Management Sciences. He is co-author with W. R. Vogel of a book on "Mathematical Programming" now in final preparation.

His memberships and honors include: Society for Advancement of Management; American Society for Quality Control; Operations Research Society; Institute of Management Sciences; Teaching Fellowship, University of Akron; Knight Memorial Scholarship, University of Akron.

WALTER PHILIP REUTHER

Vice President, AFL - CIO
President of the United Automobile, Aircraft and
Agricultural Implement Workers
Detroit, Michigan

Mr. Reuther left high school at fifteen to become an apprentice tool and die maker at the Wheeling Steel Corporation. He was fired for organizing the workers in protest against Sunday and holiday work. In February 1926, Reuther went to Detroit. He worked for Briggs, GM, Coleman Tool and Die, and finally Ford, where he worked in the tool and die room for six years.

Working nights, he completed his high school education and went three years to Wayne University, where he formed the Social Problems Club and gave its members first hand experience by taking them to picket lines when strikes were in progress. He holds honorary degrees from St. Mary's College of Oakland, California; Boston College; the University of West Virginia; Wayne University in Detroit, Michigan; and St. Francis Xavier of Antigonish, Nova Scotia.

Mr. Reuther was born in Wheeling, West Virginia, on 1 September 1907. The atmosphere of his home was one of intense interest in unions and labor problems. His father, Valentine Reuther, at the age of 23 was president of the Ohio Valley Trades and Labor Assembly and for many years an International organizer of the United Brewery Workers.

In 1933, Reuther was discharged from Ford's for labor union activity and with his brother Victor embarked on a world tour which took them through eleven countries of Europe and Asia. They worked in factories, observed the operation of auto plants and machine shops, and studied the labor movements in the countries visited. Returning to Detroit in 1935, Reuther went to work in a shop and plunged into the job of organizing auto workers. Under his leadership, West Side Local 174 of the United Automobile Workers rose from a membership of 78 in 1936 to 30,000 in 1937. In May, 1936, he was elected to the International Executive Board and was reelected to the Board every year after that. In 1942 he was first elected vice-president.

Reuther was active in the Detroit and Flint sitdowns, including the important Kelsey-Hayes Wheel strike in December, 1936, one of the early sitdown strikes in the

drive that organized the auto industry. In the forefront of the Ford organizing drive in 1937, he and other unionists were severely beaten by Ford servicemen in what has come to be known as "the battle of the overpass".

After the automobile companies were brought to a greater acceptance of unionism, Reuther worked on the problems of making collective bargaining more efficient; he was instrumenta in securing General Motors' agreement to an impartial umpire for ruling on worker-management disputes. From 1939 to 1948, Reuther was director of the GM Department of the UAW.

Reuther bucked the isolationist tides from right and left in the pre-Pearl Harbor period when in 1940 he advanced a program for converting the auto industry to a war footing and mass production of military planes. Praised by President Roosevelt, but stymied by industry leaders in Detroit and Washington, the basic elements and contentions of the "Reuther Plan", as it was popularly known, were vindicated and implemented when the auto industry finally went to war.

Reuther served as labor representative with OPM and the War Manpower Commission, but refused other appointments offered him because he objected to war-time Washington's failure to use labor in more than an advisory capacity. In the fall of 1945, following V-J Day, General Motors workers, under the direction of Reuther as head of the GM Department of the UAW, and with solid support of the whole UAW-CIO membership, made it plain that unionism had come to stay, and that the policies and objectives of American Labor were not limited to another nickel in the pay envelope.

Walter Reuther was elected President of the UAW-CIO at the Auto Worker's Tenth Convention in Atlantic City, in the latter part of March, 1946. A few months later at the Eighth Convention of the Congress of Industrial Organizations (CIO), held in Atlantic City during the week of November 18. 1946, Reuther was elected Vice President of the CIO. He was reelected to the UAW presidency by an overwhelming majority at the Union's Eleventh Convention in November, 1947.

While talking with his wife in the kitchen of their home on the night of 20 April 1948, shortly after returning from a meeting of the UAW Executive Board, Reuther was felled by a shotgun blast from an assailant who fired through a rear window. Reuther's right arm was almost severed and his chest wounded. As of this date, Reuther's assailants have not been apprehended.

WALTER PHILIP REUTHER (Continued)

Under Reuther's leadership, following the 1949 UAW-CIO Convention in Milwaukee, the Union launched a campaign to win employer-financed pensions and health insurance for its members. The first such program was achieved in negotiations with the Ford Motor Company in September, 1949. Since that time more than 1,000,000 members of the UAW-CIO have been covered by pensions wholly financed by employers, and by health insurance plans for which the employer pays at least half the cost.

When the International Confederation of Free Trade Unions was founded in London, December, 1949, Reuther attended the founding session as chairman of the CIO delegation. Earlier that month, at a meeting in Zurich, Switzerland, he was elected President of the Automobile Division of the International Metalworkers Federation.

In addition to his other union activities, Reuther serves as Co-Director with William Oliver, of the UAW-CIO Fair Practices and Anti-Discrimination Department, set up at the Tenth UAW Convention by constitutional amendment. He is also a member of the Executive Boards of the National Association for the Advancement of Colored People, the Religion and Labor Foundation and a member of other organizat

On 4 December 1952, Reuther was elected President of the Congress of Industrial Organizations to succeed the late Philip Murray. He was reelected President of the CIO in 1953 and 1954. He played a leading role in the negotiations for labor unity between the CIO and AFL which resulted in February, 1955, in a merger agreement which was subsequently consummated. At the recent convention which saw the merger of the AFL and CIO brought to realization, Reuther was elected Vice President of the newly united organization.

Reuther is married, has two young daughters, and lives in Detroit.

DR. ANDREW S. SCHULTZ, Jr.

Director of Research for the American Institute of Industrial Engineers, and Head, Department of Industrial and Engineering Administration, Cornell University, Ithaca, New York

Dr. Schultz is Professor and Head, Department of Industrial and Engineering Administration, Sibley School of Mechanical Engineering, Cornell University, Ithaca, N.Y; Director of Research of the American Institute of Industrial Engineers; Associate Editor of the Journal of the Operations Research Society of America; Consultant to a number of industrial firms; Member of Am. Soc. Engineering Educ.; Inst. Management Science; Am. Stat. Assoc.; Am. Soc. Quality Control; Nat'l. Assoc. Cost Accountants; A.I.I.E.; and O.R.S.A.

JOHN L. SCHWAB

President, John L. Schwab Associates
Management Consultants
Bridgeport, Connecticut

As president of John L. Schwab Associates, John L. (Jack) Schwab and his firm of consultants have achieved international recognition for many contributions to the field of industrial management and engineering.

Mr. Schwab is co-originator of Methods-Time Measurement -- the well-known technique of cost reduction through work simplification which permits the setting of performance standards without use of the stop watch. He is also co-author of the McGraw-Hill published textbook, "Methods-Time Measurement" (1949) -- and is now readying "MTM in Materials Handling."

Mr. Schwab and his organization have twice been featured in FORTUNE magazine, and have also been acclaimed in such other publications as FACTORY, MODERN INDUSTRY, MILL AND FACTORY, and others.

A recognized expert in the field of manufacturing, production, and management engineering, Mr. Schwab has installed cost-reducing procedures in virtually every type of industry throughout the U. S., Canada, and Europe, including companies with nationally and internationally known names.

He has also done outstanding work in the educational and training fields and is on the Executive Committee of the Bridgeport Engineering Institute. Mr. Schwab's firm has pioneered development work in several other management areas, and now sponsors in-plant training programs in Management Development and Human Relations, Industrial Relations, Management Fundamentals, and Speech.

Before forming his own firm Mr. Schwab was Vice President, Methods Engineering Council, New England Division, Bridgeport, Connecticut. Prior to this he was on Headquarters Industrial Engineering Staff, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania, and later was Chief Industrial Engineer with Bryant Electric Company, Bridgeport, Connecticut.

Mr. Schwab was a founder and first president of Bridgeport Chapter, Society for Advancement of Management, and is a National Director of this organization. He was chief contributor to the paper on Work Measurement presented at the 9th International Management Congress in Brussels, Belgium, at which he was a U. S. representative.

JOHN L. SCHWAB
(Continued)

Mr. Schwab has addressed many professional societies (American Society of Tool Engineers, American Society of Mechanica Engineers, Society for the Advancement of Management, National Association of Cost Accountants, Controllers Institute, and so on). He also has delivered special lectures at Wharton School,' University of Pennsylvania, Acton Technical College, London, England, and the University of Birmingham, England. In addition he has addressed numerous technical societies in both Belgium and France.

DR. ROBERT B. SLEIGHT

President, Applied Psychology Corporation
Washington, D. C.

Dr. Sleight has been engaged in human engineering research and consulting for the last nine years. After serving as a naval aviator during World War II, he received the Ph.D. degree from Purdue University with a major course of study in industrial and experimental psychology. Dr. Sleight was formerly Assistant Professor and Research Psychologist at The Johns Hopkins University. Since 1952 he has been President of the Applied Psychology Corporation located in Washington, D. C.

C. LLOYD THORPE

General Manager, Willamette Iron and Steel Company
(a division of Guy F. Atkinson Company)
Portland, Oregon

Mr. Thorpe received BBA and MBA degrees at the University of California, Golden Gate College.

He was Assistant Chief Engineer, Ray Oil Burner Company, 1934-39; V. P., Combustion Utilities, Inc., 1939-40; Chief Engineer, International Totalizer Company, 1940-44; Plant Manager, Dalmo Victor, 1944-45; General Manager, Clarkson Company, Project Manager, Works Manager, Dalmo Victor, 1945-47; Management Consultant, 1947-48; General Personnel and Public Relations Manager, Guy F. Atkinson Company, 1948-1954; Consulting Technical Editor, Western Industry, 1949-54; and has been General Manager, Willamette Iron and Steel Company, since 1954.

He has been Director, Portland Chamber of Commerce, since 1956; Director, Junior Achievement of Portland, Inc., since 1955; and Director, Goodwill Industries of Oregon, since 1956.

Mr. Thorpe was Lecturer, Stanford University E.S.M.W.T., 1944-45; Lecturer, Golden Gate College, 1946-54; Lecturer, Graduate School of Credit and Financial Management, Stanford University, 1954; Member and Secretary, City of San Mateo Personnel Board, 1944-46; School of World Business Technical Advisory Committee, San Francisco State College, 1948-54. He is a registered Professional Engineer, California.

He is a member of American Society of Mechanical Engineers, American Institute of Industrial Engineers, American Society of Training Directors; Society for Advancement of Management; Pacific Northwest Personnel Management Assn.; Rotary International, Commonwealth Club of California, Multnomah Athletic Club, and University Club of Portland.

Mr. Thorpe's biography is in Who's Who in Engineering, Who's Who in American Education, Who's Who in Commerce and Industry, Who's Who in the West, International Blue Book.

DONALD H. VANCE

Vice President and Executive Engineer
The Korfund Company, Inc.
Long Island City, New York

Mr. Vance is a graduate of the University of Michigan in Mechanical Engineering.

He worked for two years in the Engineering Research Department of the University of Michigan before joining the staff of the Korfund Company with whom he has been associated for over 13 years.

Mr. Vance is the author of many technical papers and articles. He is the author of the section on "Vibration Control and Noise Silencing" in the Plant Engineer's Handbook, a McGraw-Hill publication. His paper on "The Use of Vibration and Shock Control in Reducing Noise Levels" presented at the 6th National Noise Abatement Symposium was published in the March issue of "Noise Control" Magazine. He has been an active speaker for ASTE, ASME, ASH and AE.

Mr. Vance is a member of Tau Beta Pi and Phi Kappa Phi.

DR. RAYMOND VILLERS

Consultant in Industrial Management, and
Associate Professor of Industrial Engineering at
Stevens Institute of Technology
Hoboken, New Jersey

Of French-American ancestry, Dr. Villers was born in France and graduated from the Sorbonne, University of Paris. He has received graduate degrees from several universities, including Columbia. During World War II, as a reserve officer in the French Forces, Dr. Villers served on the Personal Staff of the Admiral Commander-in-Chief of the Free French Navy. Later during the war he served with the United States Navy and became an American citizen.

Dr. Raymond Villers, Consultant in Industrial Management, Associate Professor of Industrial Engineering at Stevens Institute of Technology and Lecturer in Industrial Engineering at Columbia University, has been engaged for many years in intensive research work in industrial organization, production planning and profit control. He was Assistant Professor of Industrial Engineering at Columbia University from 1947 to 1952. In 1946 he received the Du Pont de Nemours - General Motors Joint Fellowship of Research which started his research activities.

DR. RAYMOND VILLERS (Continued)

He is the author of The Dynamics of Industrial Management (1954), of scientific papers and articles and with the late Dr. Walter Rautenstrauch of the Economics of Industrial Management (1949) and Budgetary Control (1950). He is a contributing author to Grant and Ireson's Handbook of Industrial Engineering and Management (1955) and has published articles in such magazines as The Journal of Industrial Engineering, Advanced Management, Dun's Review and Modern Industry, and Harvard Business Review.

Dr. Villers lectured for the United States Army in 1949, the United States Navy in 1950-51, the United States Air Force in 1955 and the United States Civil Service in 1954 and 1955 and before many professional societies throughout the country. He is a Trustee of Marlboro College, a member of AIIE, ASME, ASEE and other professional societies. He is an honorary member of Alpha Pi Mu and was elected vice-president for 1952 for the North-Eastern Region of the AIIE. He is also a member of the New York Academy of Sciences, the American Association of University Professors, the Newcomen Society of England, and the American Institute of Management.

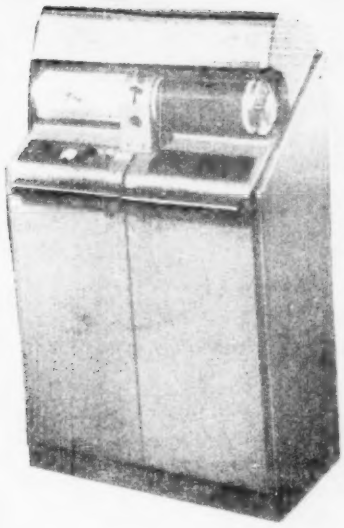
For many years Dr. Villers was a close associate of Dr. Rautenstrauch, one of the pioneers in the promotion of scientific methods in industrial management, and now heads the firm of Rautenstrauch and Villers, consultants in Industrial Management.

STROTHER H. WALKER

Research Group Chairman, Operations Research Office
The Johns Hopkins University
Chevy Chase, Maryland

r. Walker is a graduate of Harvard University.

e has had 20 years experience in administration, management nalysis and systems development in heavy industry and logistics. e joined the staff of the Operations Research Office of The ohns Hopkins University in 1954. Previously, he had been ssociated with the Vanadium Corporation of America, the athieson Chemical Corporation, and Payrolls and Tabulating, Inc. e was the manager of the latter firm. Mr. Walker is presently onducting studies in the field of military logistics and electro omputer applications.



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